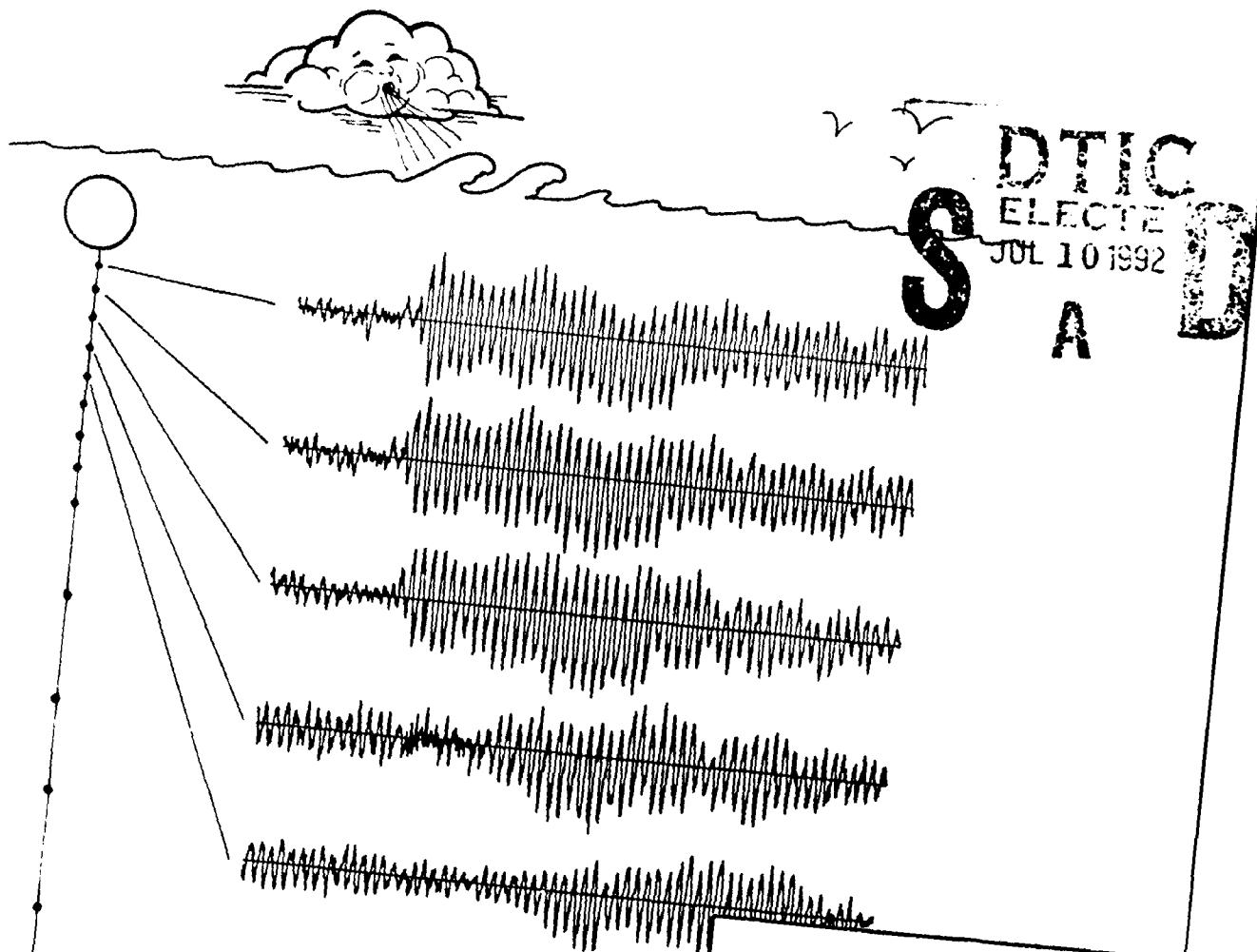


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OBSERVATIONS FROM THE
C1 MOORING DURING OCEAN
STORMS IN THE N.E.
PACIFIC OCEAN,
AUGUST 1987-JUNE 1988

by

Murray D. Levine
Clayton A. Paulson
Steve R. Gard
Jay Simpkins
Vassilis Zervakis

Reference 90-3
April 1990
Data Report 151

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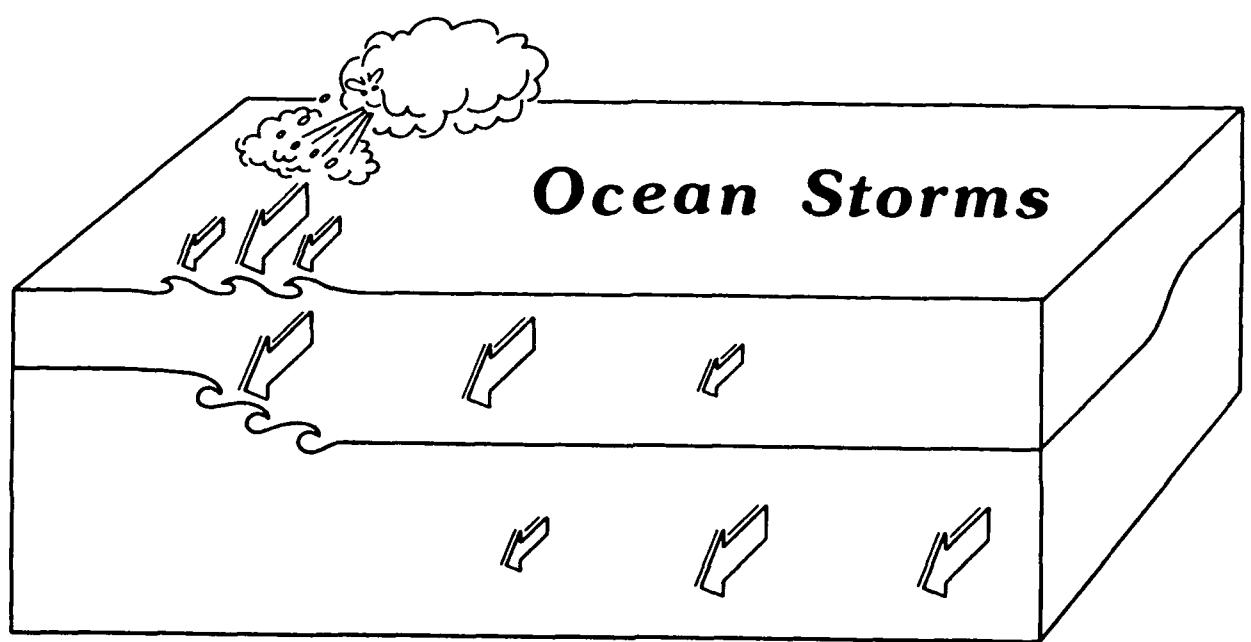
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**Observations from the C1 Mooring
during OCEAN STORMS
in the N.E. Pacific Ocean, August 1987–June 1988**

Murray D. Levine
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INTRODUCTION

This report presents moored observations of velocity, temperature, conductivity and pressure, made as part of the Ocean Storms experiment, conducted in the N.E. Pacific Ocean from August 1987 to June 1988.

The main objective of Ocean Storms is to study the three-dimensional response of the upper ocean to severe storms. To meet this objective, a variety of observations were made from sensors on moorings, drifters and aircraft. The aim was to measure simultaneously the horizontal variability of the atmospheric forcing and the oceanic response. The observations reported here represent one component that will be used in a comprehensive analysis of the entire Ocean Storms data set.

The specific goals of this project are:

- To investigate the generation of near-inertial waves by wind forcing,
- To investigate the thermal response in the seasonal thermocline to surface forcing,
- To investigate the response of deep currents to fluctuations of wind stress curl,
- To determine if there is any response to storms of internal waves in the main thermocline,
- To resolve the temporal variability and vertical structure of the internal tide, and
- To resolve the mesoscale variability.

INSTRUMENTATION

Description

A single mooring was deployed in the N.E. Pacific Ocean at site C1 ($47^{\circ} 25.4' N$, $139^{\circ} 17.8' W$) as part of the Ocean Storms moored array (Figure 1). The site is located about 1100 km west of the Washington coast with a water depth of 4225 m. The mooring was deployed from the R/V Melville on 20 August 1987; recovery was made from the same ship 10 months later on 25 June 1988.

The mooring contained a total of 14 current meters, 4 thermistor chains and 5 temperature-conductivity recorders (Figure 2). The shallowest mooring element was a steel sphere at 57 m; a subsurface design was selected to reduce contamination of current meter observations due to mooring motion. Three types of current meters were used: 7 VMCMs that use dual propellers (manufactured by EG&G), 5 RCM-5s that use a Savonius rotor and vane (manufactured by Aanderaa), and 2 S-4s that measure the electric field (manufactured by InterOcean). The VMCMs and RCM-5s also recorded temperature. The 4 thermistor chains (manufactured by Aanderaa) consisted of 11 thermistors distributed evenly over the length of the chain. The 5 Seacat temperature-conductivity recorders (manufactured by Seabird Electronics) measured temperature and conductivity time series at a single point; the upper two instruments also contained a Digi quartz pressure sensor (manufactured by Paroscientific, Inc.). The pressure records were used to determine sensor depths and to monitor mooring motion. Also, an upward-looking acoustic sensor (WOTAN), to measure surface wind speed, was attached to the mooring for Bill Large. Two acoustic releases (manufactured by EG&G) were used at the bottom to release the anchor for recovery.

Also included in this report are data from one additional Aanderaa thermistor chain that was attached to the surface mooring deployed by Scripps Institution of Oceanography at site W ($47^{\circ} 28.04' N$, $139^{\circ} 59.23' W$), located about 50 km to the west of C1. The 11 thermistors were distributed from 9 to 105 m below the surface.

Technical details about the instruments, including sampling intervals and serial numbers, are presented in Tables 1 to 4. The data recovery was nearly 90%. Figure 3 is a time line showing the period of successful operation for each instrument.

Calibration

VMCM Temperature. The VMCMs were modified to record over a temperature range from 4 to 15° . All instruments were calibrated before deployment and

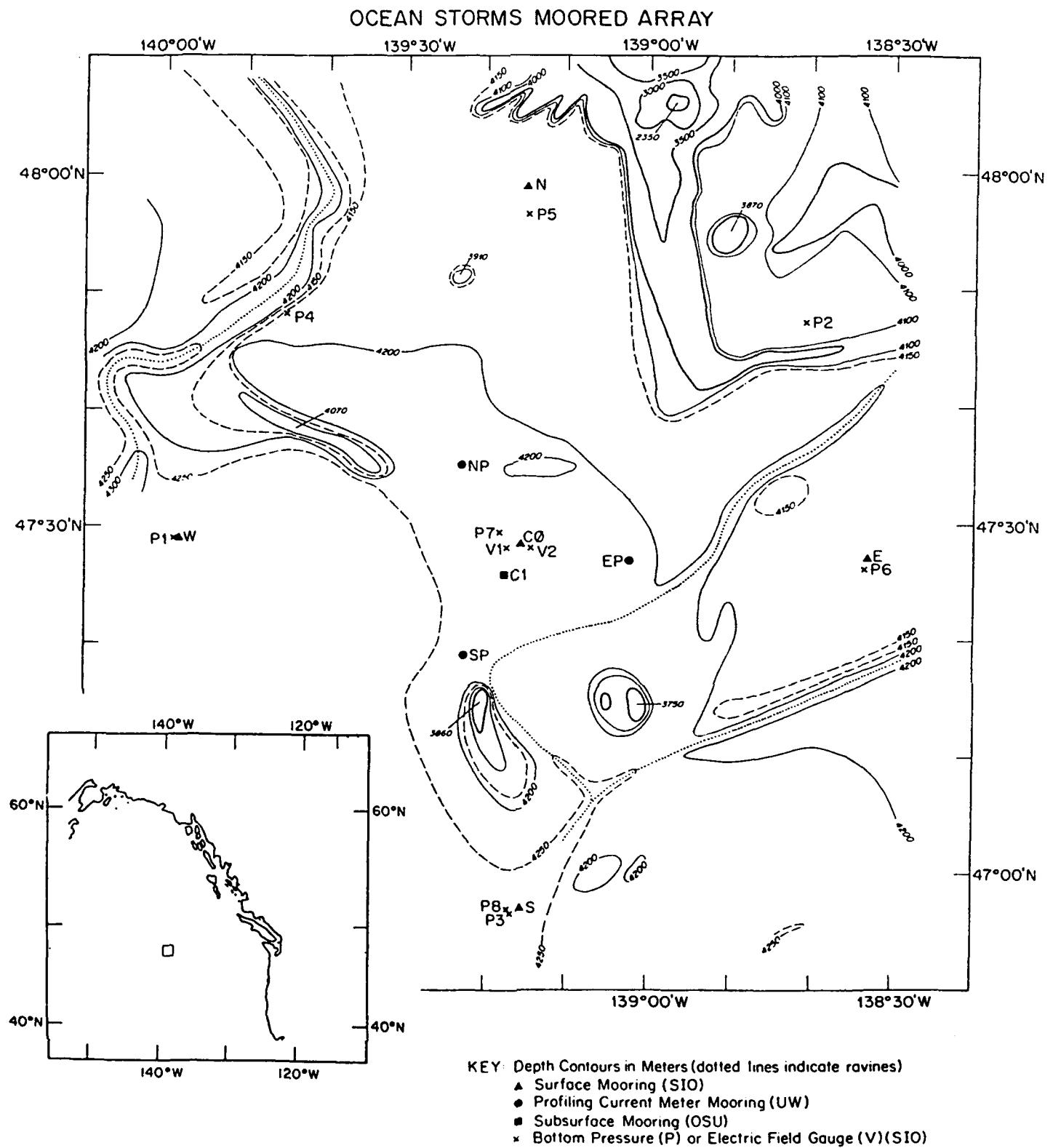


Figure 1. Chart showing location of all moorings deployed during Ocean Storms (courtesy of C. Eriksen).

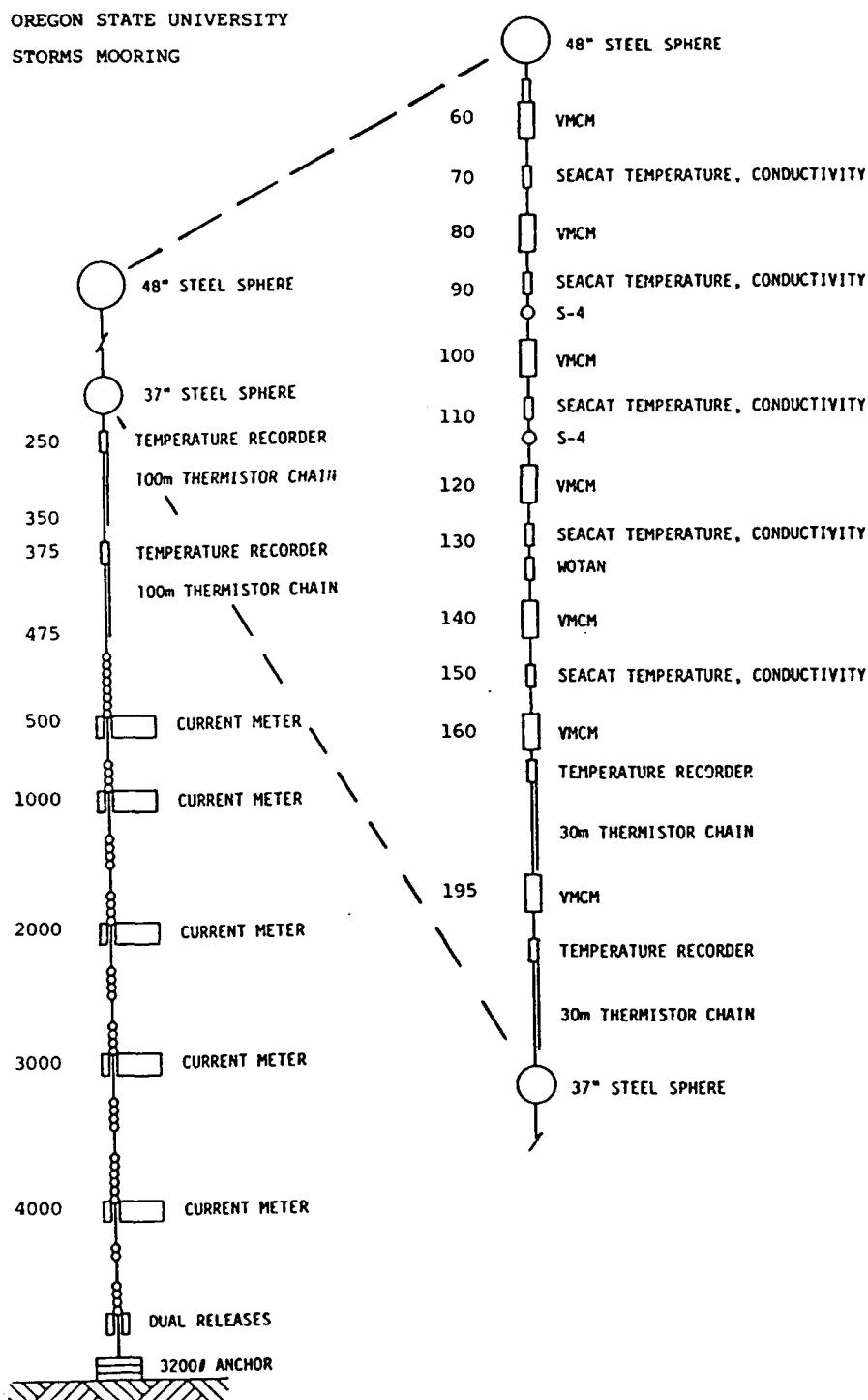


Figure 2. Schematic diagram of the mooring deployed at site C1.

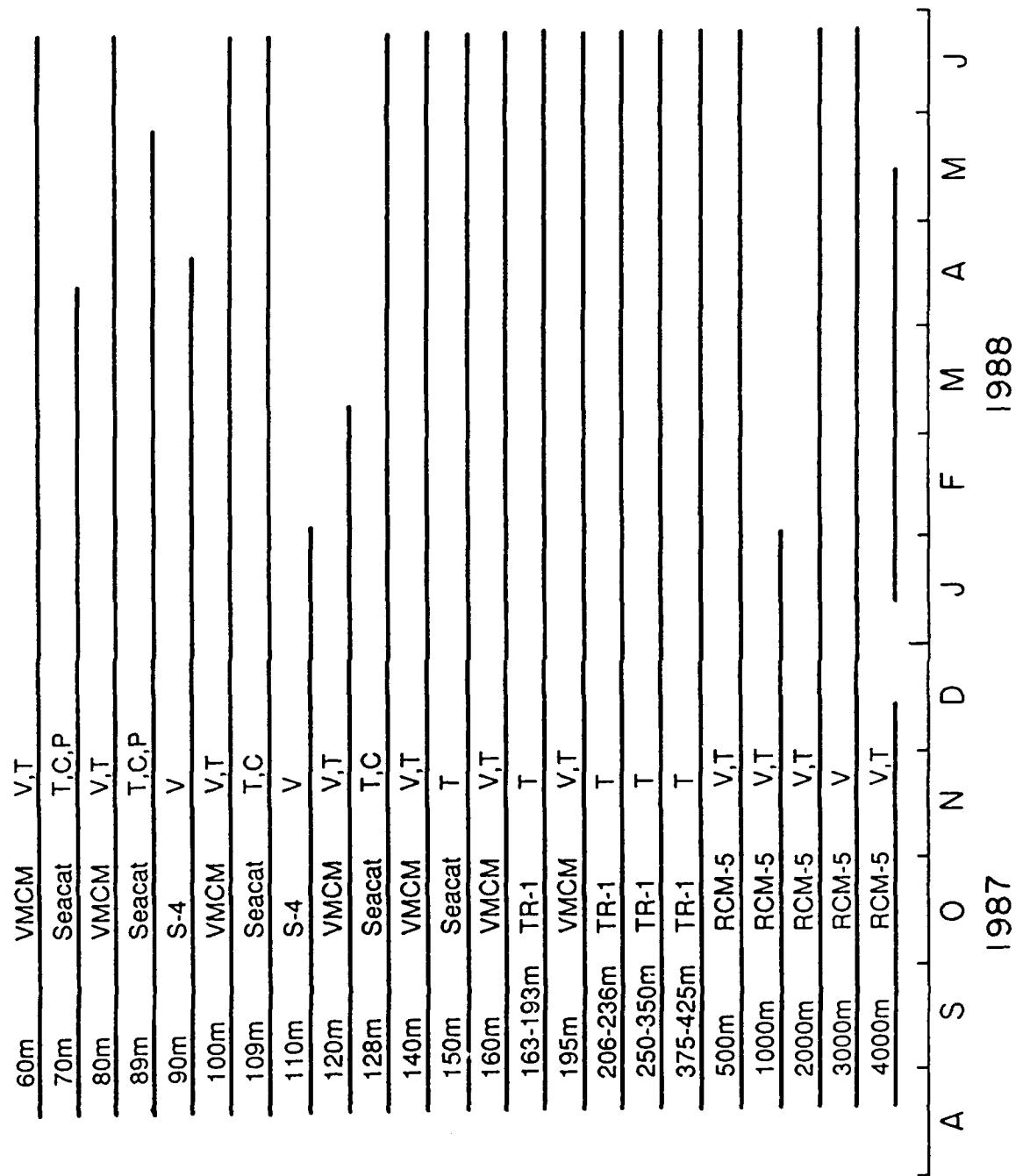


Figure 3. Time interval that velocity (V), temperature (T), conductivity (C) and pressure (P) were recorded from VMCMs (current meters manufactured by EG&G), TCM-5s (current meters manufactured by Aanderaa), S-4s (current meters manufactured by Inter Ocean), Seacats (temperature-conductivity recorders manufactured by Seabird), TR-1 (thermistors chains manufactured by Aanderaa).

Depth, m	Serial No./ Tape No.	Temperature Range	Sampling Interval	Temperature Calibration Differences,* units: 10^{-3} °C		Compass Calibration, Range of deviation from true, degrees (Pre-Storms/Post-Storms)
				6°C	10°C	
60	203504/3	4 - 15°	15 min.	-10	-6	-2.6 to 8.8 / -0.4 to 7.7
80	401205/5	4 - 15°	15 min.	-5	-2	0.2 to 6.3 / -1.0 to 5.5
100	203203/3	4 - 15°	15 min.	-4	-2	-5.4 to 0.7 / -3.0 to 1.5
120	203304/3	4 - 15°	15 min.	-7	-3	-5.2 to 1.8 / -4.0 to 4.9
140	202803/3	4 - 15°	15 min.	3	5	-0.5 to 9.0 / -0.2 to 10.2
160	401105/5	4 - 15°	15 min.	-4	-2	-1.0 to 3.4 / -2.6 to 3.4
195	401004/4	4 - 15°	15 min.	-5	-1	-1.0 to 2.1 / -1.3 to 2.1

*Differences between post-Storms and pre-Storms calibrations.

Table 1. Technical information about EG&G VMCMs (Vector Measuring Current Meters) deployed during Ocean Storms.

Depth, m	Serial No./ Tape No.	Temperature Range Configuration	Pressure Sensor Range, psi	Sampling Interval, hours	
		Channel 2	Channel 4		
500	6974/15	-2.6 to 5.6° (Arctic Range)	3.1 to 5.1° ($R_h = 4546\Omega$) ($R_l = 4964\Omega$)	0-1500	1
1000	5883/18	-2.6 to 5.6° (Arctic Range)	2.0 to 3.0° ($R_h = 4987\Omega$) ($R_l = 5213\Omega$)	0-3000	1
2000	5884/8	0 to 20° (Std. low range)	1.5 to 2.5° ($R_h = 5097\Omega$) ($R_l = 5329\Omega$)	0-5000	1
3000	1241/46	0 to 20° (Std. low range)	1.1 to 2.1° ($R_h = 5186\Omega$) ($R_l = 5423\Omega$)	0-5000	1
4000	1236/53	0 to 20° (Std. low range)	1.1 to 2.1° ($R_h = 5186\Omega$) ($R_l = 5423\Omega$)	0-8000	1

Table 2. Technical information about Aanderaa RCM-5 current meters deployed during Ocean Storms.

Depth, m	Serial No.	Pressure Sensor* Serial No.	Battery Type	Sampling Interval	Temperature Calibration	
					Differences,** Units= $\times 10^{-3}$ °C	Mean Std. Dev.
70	161415-50	21449	Electrochem Lithium "D", 4 ea.	6 min before 3/5/88 12 min after 3/5/88	2.8	1.3
89	161415-51	21432	Electrochem Lithium "D", 4 ea.	6 min before 3/5/88 12 min after 3/5/88	1.8	1.0
109	161415-40	N/A	Duracell "D" 6 ea.	6 min before 3/5/88 12 min after 3/5/88	2.5	1.6
128	161415-41	N/A	Duracell "D" 6 ea.	6 min before 3/5/88 12 min after 3/5/88	2.3	1.2
150	161415-43	N/A	Duracell "D" 6 ea.	6 min before 3/5/88 12 min after 3/5/88		

* Parascientific Digiquartz, Model 8600, 0-600 meters.

** Differences between post-Storms and factory calibrations.

Table 3. Technical information about Seabird Seacat temperature-conductivity recorders deployed during Ocean Storms.

Table 4. Technical information about Aanderaa thermistor chains deployed during Ocean Storms.

Depth of shallowest-deepest thermistor, m	Serial No./Tape No. of TR Recorder	Chain No./Encoder No./Electronic Board No.	Recorder Configuration	Bridge Resistors, WR1/WR4, ohms	Sampling Interval, Hours
			Range, °C	Resolution, °C	
9-105†	768/11	1083/9751/731*	-2.5 to 21.5°	0.024°	2000/3825 3
163-193	269/21	687/4222/1061**	2.5 to 10.5°	0.078°	9536/4284 2
206-236	265/31	1479/4223/1058**	2.5 to 9.0°	0.063°	12177/4419 2
250-350	8/22	1480/ 711/1057**	3.0 to 7.4°	0.043°	18372/4532 2
375-475	268/22	1084/6522/54*	2.9 to 9.0°	0.060°	12877/4386 2

* Model No. 2167

** Model No. 2167BS

† On Scripps West Mooring

after recovery at OSU. Over the temperature range of interest, the difference between the post- and pre-Storms calibrations were typically less than 0.005°C; the two instruments at 60 and 100 m showed slightly higher differences (see Table 1). The data were converted using the pre-Storms calibrations.

VMCM Velocity. Compass calibrations were performed before and after deployment at OSU. Differences between pre- and post-Storms calibrations were small (Table 1). When rotated, the maximum deviation of the compass from the true value was found to be 10°—for some instruments it was less than 5° (Table 1).

RCM-5 Temperature. The RCM-5s recorded temperature from a single thermistor in both channels 2 and 4. The temperature resolution in channel 4 was increased from the factory value by replacing resistors in the bridge network. The temperature range of channel 4 was selected for each instrument based on historical data (see Table 2). Pre-Storms calibrations were performed at OSU and used to convert the data. Temperature at 3000 m (#1241) failed due to a broken wire.

RCM-5 Velocity. Compass calibrations were performed before and after deployment at OSU on instruments #6974, #5883 and #5884; differences of less than 1 degree were observed. Instruments #1241 and #1236 were calibrated only before deployment. On #1236 at 4000 m the speed sensor went bad for a continuous 29-day period in December-January. The sensor apparently recovered, however, some caution is advised as the cause of this behavior is unknown. All channels were bad on #1236 from mid-May till the end.

Seacat Temperature. These instruments were new at the time of the deployment; therefore, factory calibrations were used to convert the data. A post-Storms calibration was performed at OSU. Temperature differences between factory and post-Storms calibrations were between .0018 and .0028°C (see Table 3).

Seacat Conductivity. These instruments were new at the time of the deployment; therefore, factory calibrations were used to convert the data. A post-Storms intercomparison was performed and indicated that all the sensors were within 0.002 Siemen/m of each other. This was not a full calibration as the bath was not referenced to an absolute standard conductivity. The conductivity cell at 150 m (#161415-43) failed early in the deployment.

Thermistor Chains. The thermistor chain and recorder attached to the Scripps' mooring at site W (recorder #768, chain #1083) was configured to record over the standard range of -2.5 to 21.5°C, yielding a least count resolution of 0.024°.

The four chains attached to the mooring at C1 were modified to record at increased resolution by replacing resistors in the bridge circuit (see Table 4). Two

problems were encountered in the instruments when the temperature ranges were narrowed: an increase in digitization noise due to self heating of the thermistors and occasional "jumps" in temperature. The self-heating problem has been studied previously and has been reduced as much as possible by using a modified electronic board (model no. 2167BS) supplied by Aanderaa that reduces the amount of time the thermistor is powered. The amount of noise introduced by self-heating is different for each thermistor. This noise does not appear to be significant in the plots shown here. The second problem of occasional "jumps" is more troublesome. These shifts appeared a few times in recorders #265 and #268 during long-term tests. They were so infrequent that they could not be predicted. It does not appear that such shifts affect the plots. However, the possibility that "jumps" have occurred needs to be considered if a more detailed analysis of these series is attempted.

Calibrations were performed for all chains at OSU both before deployment and after recovery. A comparison of the two calibrations is described below.

Recorder No./Chain No.

#269/#689 Over the range of 6 to 7°C the difference between post- and pre-Storms calibration was between -.025 and -.035°C for all thermistors. Post-Storms calibrations were used.

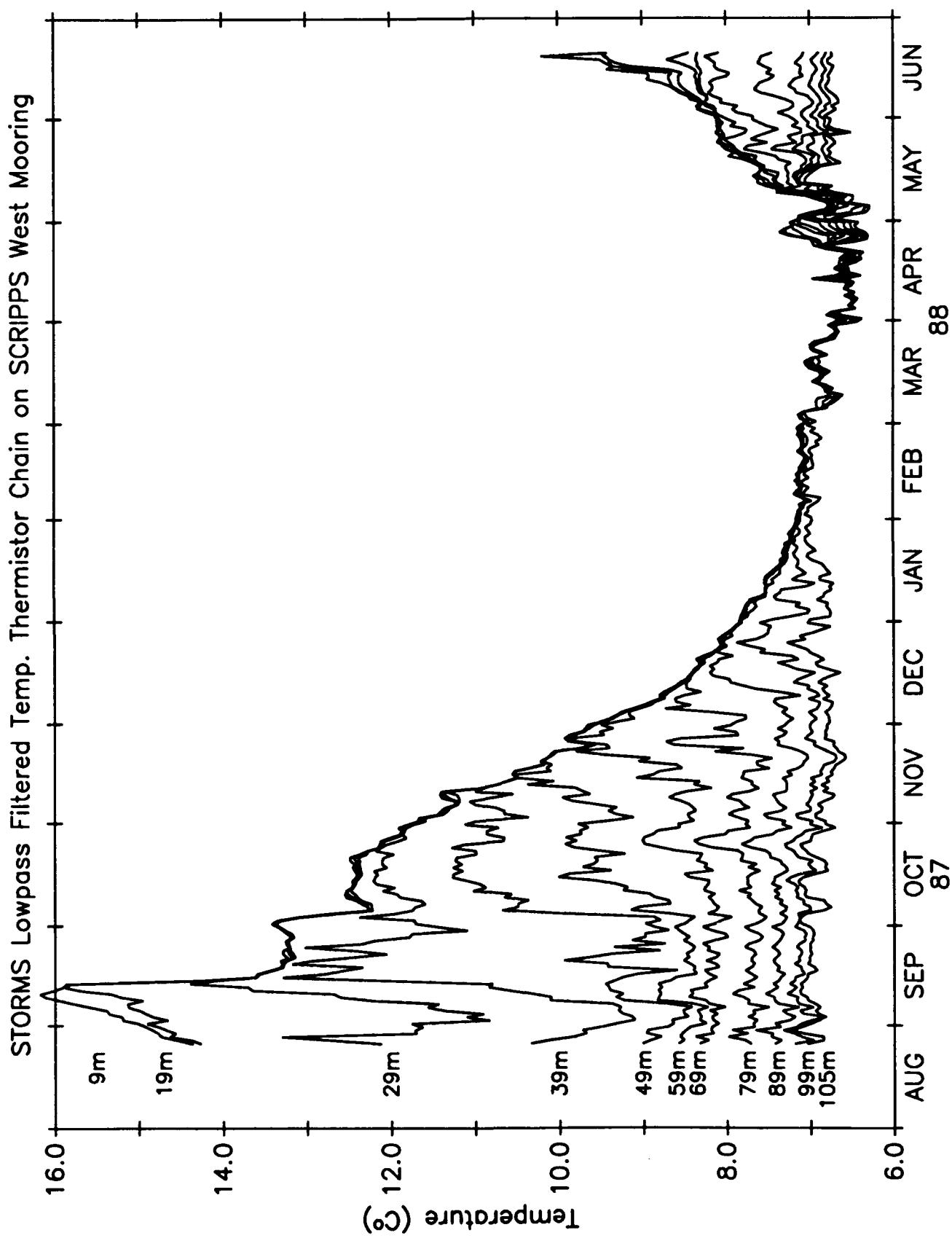
#265/#1479 Over the range of 5.5 to 7°C the difference between post- and pre-Storms calibrations was nearly -.035°C for thermistors #1 to 10 and about -.05° for thermistor #11. Pre-Storms calibrations were used.

#8/#1480 Over the range of 4.5 to 6.5°C the difference between post- and pre-Storms calibrations was between -.02 and -.03°C for all thermistors except #5 and #10 which had differences of -.05 and -.04 respectively. Pre-Storms calibrations were used.

#268/#1084 Over the range of 4.5 to 6.5°C the difference between post- and pre-Storms calibrations increased systematically for thermistors further from the recorder. Differences between -.01 and -.03°C were found for thermistors #1 to 5, and differences of -.04 to -.05 for thermistors #6 to 11. Differences in calibration in thermistors #6 to 11 were large relative to the temperature range and therefore were not plotted. Post-Storms calibrations were used.

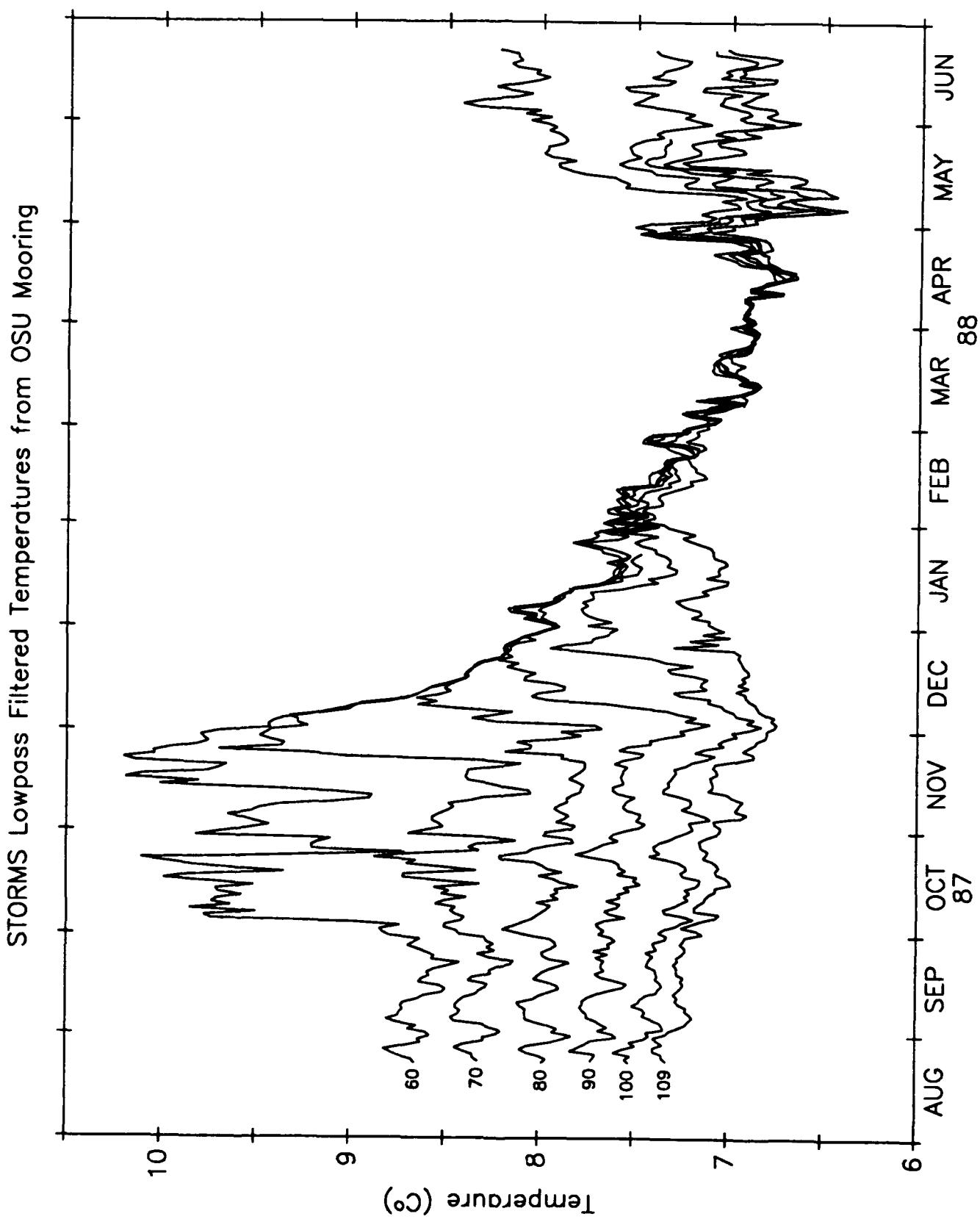
TIME SERIES OF TEMPERATURE: LOW-PASS FILTERED

Observations are from thermistor chain on Scripps' mooring at site W. Data are low-pass filtered (40 hour half-power) and decimated to daily values.



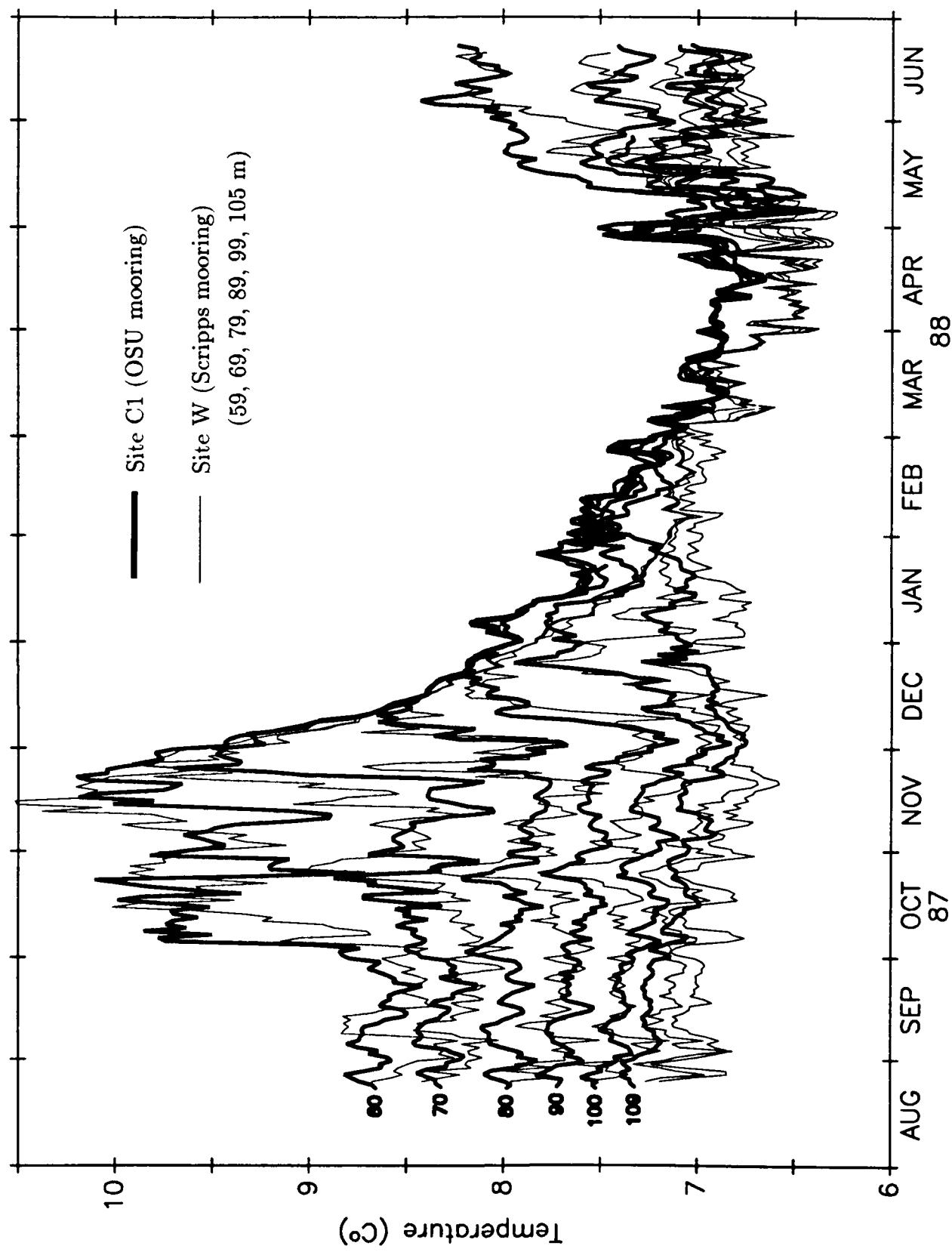
TIME SERIES OF TEMPERATURE: LOW-PASS FILTERED

Observations are from VMCMs at 60, 80, and 100 m and from Seacats at 89 and 109 m. Data are low-pass filtered (40 hour half-power) and decimated to daily values.



TIME SERIES OF TEMPERATURE: LOW-PASS FILTERED

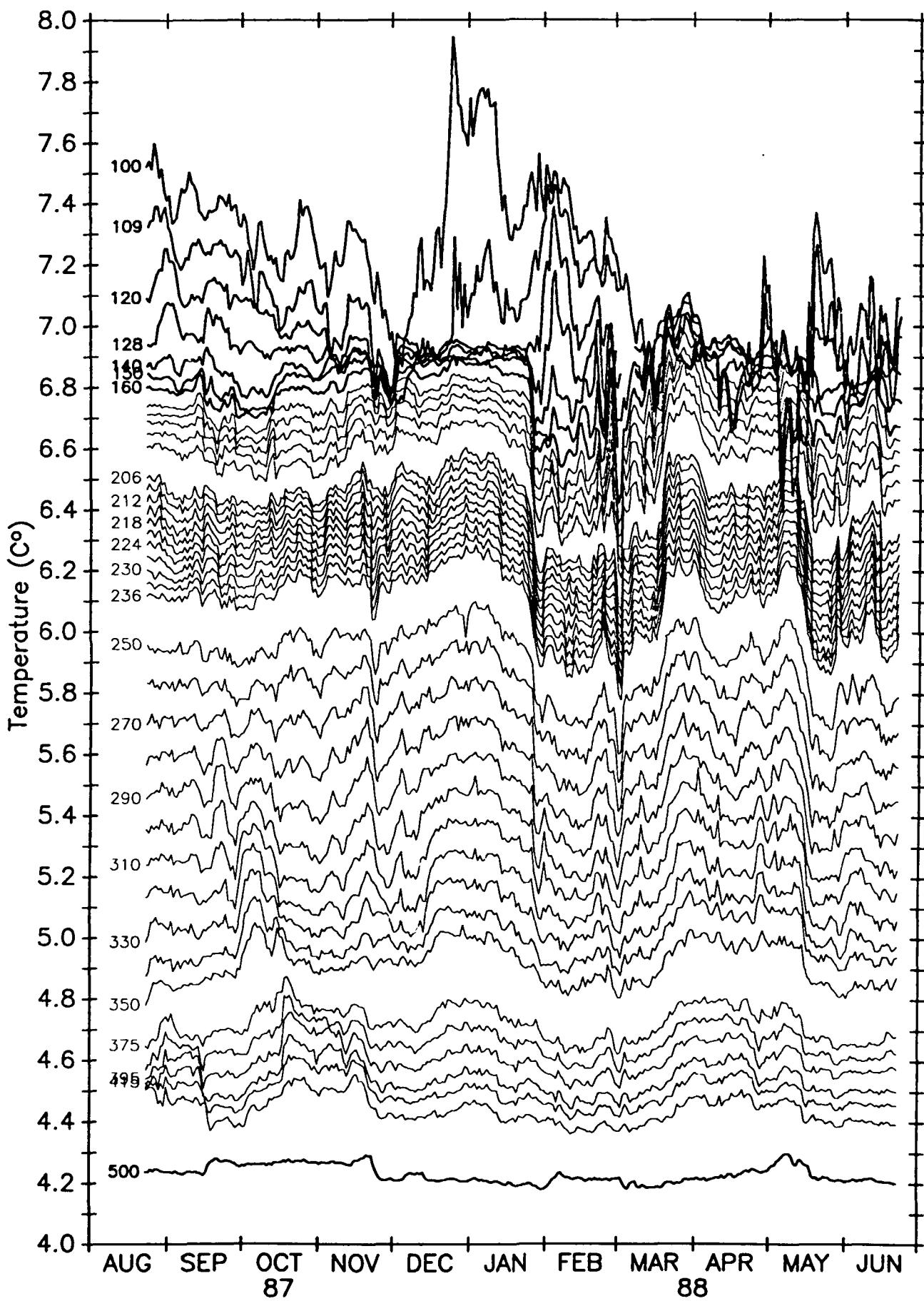
This plot compares temperature measured at site W and C1 over the depth range from 60 to 109 m. Observations from site W are from the thermistor chain on the Scripps' mooring; observations from site C1 are from VMCMs at 60, 80, and 100 m, and from Seacats at 89 and 109 m. Data are low-pass filtered (40 hour half-power) and decimated to daily values.

STORMS Lowpass Filtered Temperatures from OSU and SCRIPPS Moorings

TIME SERIES OF TEMPERATURE: LOW-PASS FILTERED

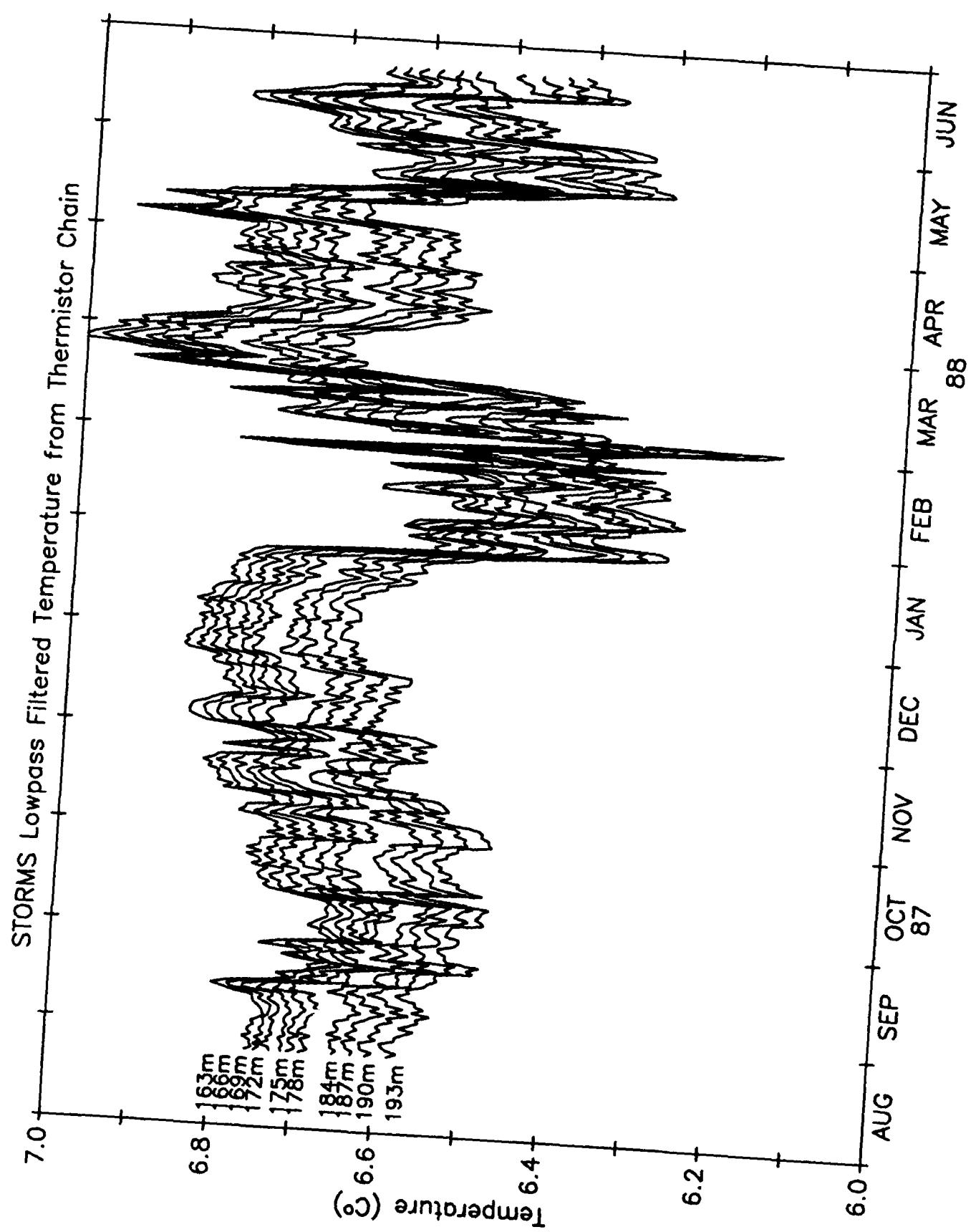
Observations from 100 to 500 m from VMCMs at 100, 120, 140 and 160 m; from Seacats at 109, 128 and 150 m; from thermistor chains spanning 163-193 m, 206-236 m, 250-350 m, and 375-425 m; and from an RCM-5 at 500 m. Data are low-pass filtered (40 hour half-power) and decimated to daily values.

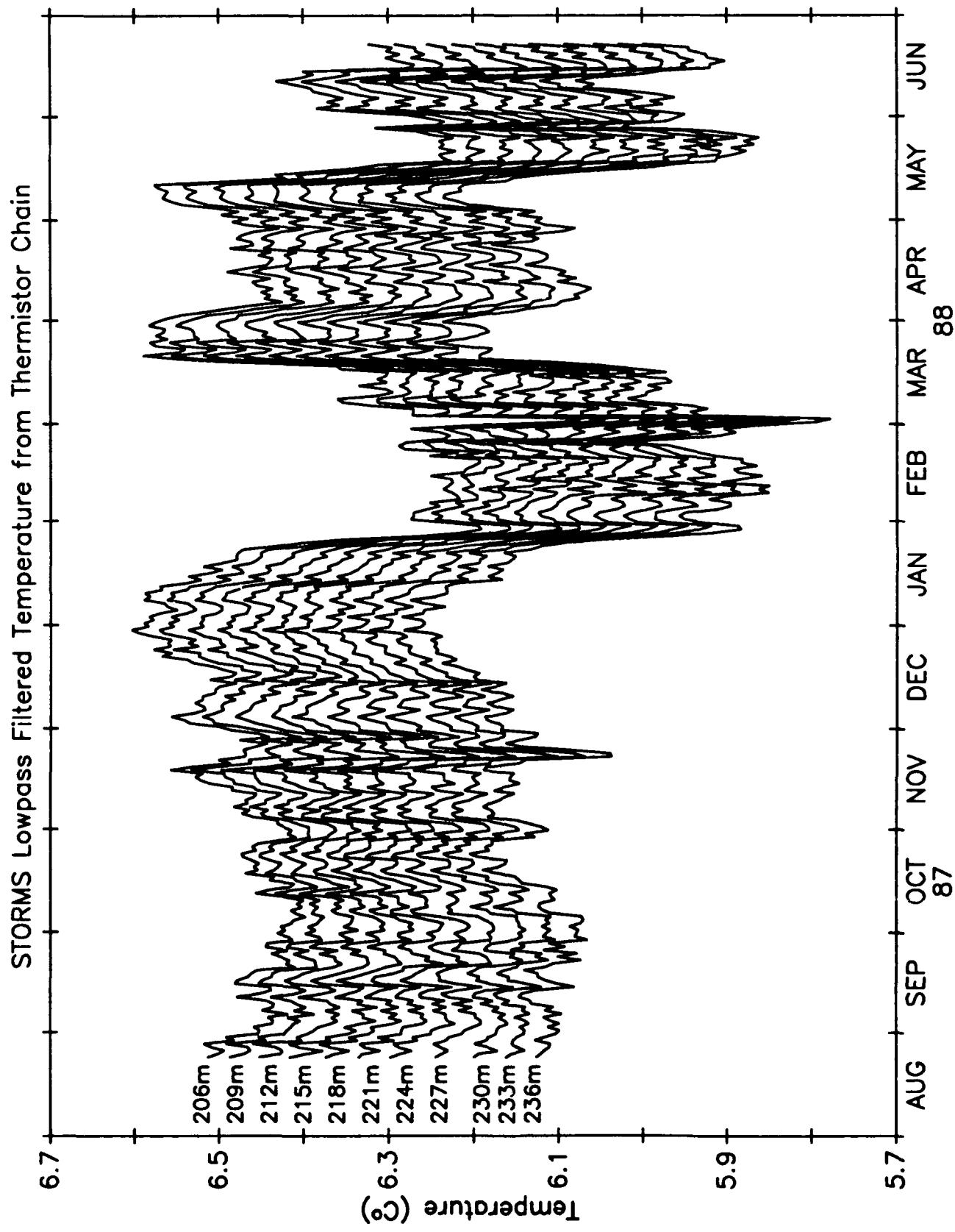
STORMS Lowpass Filtered Temperatures

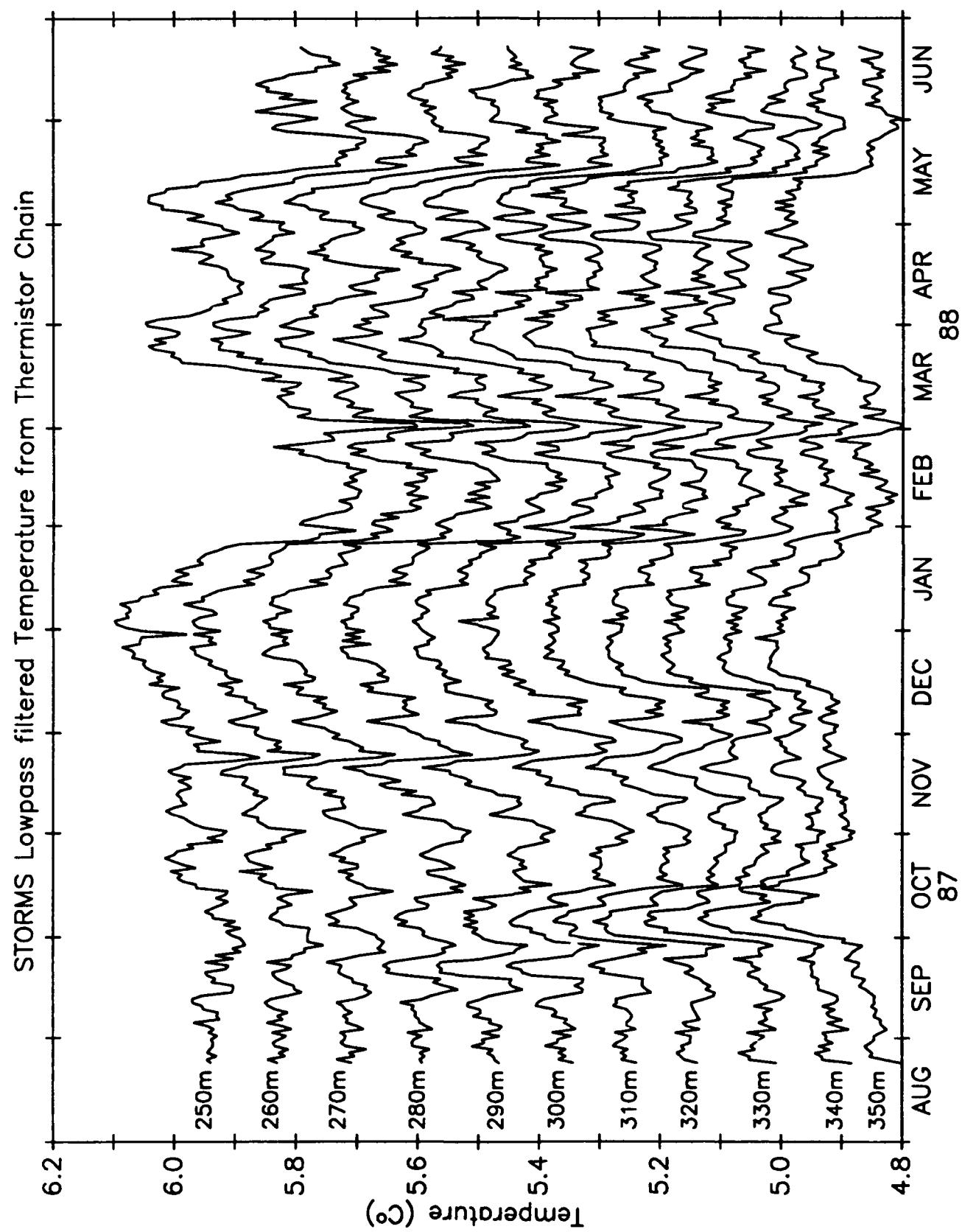


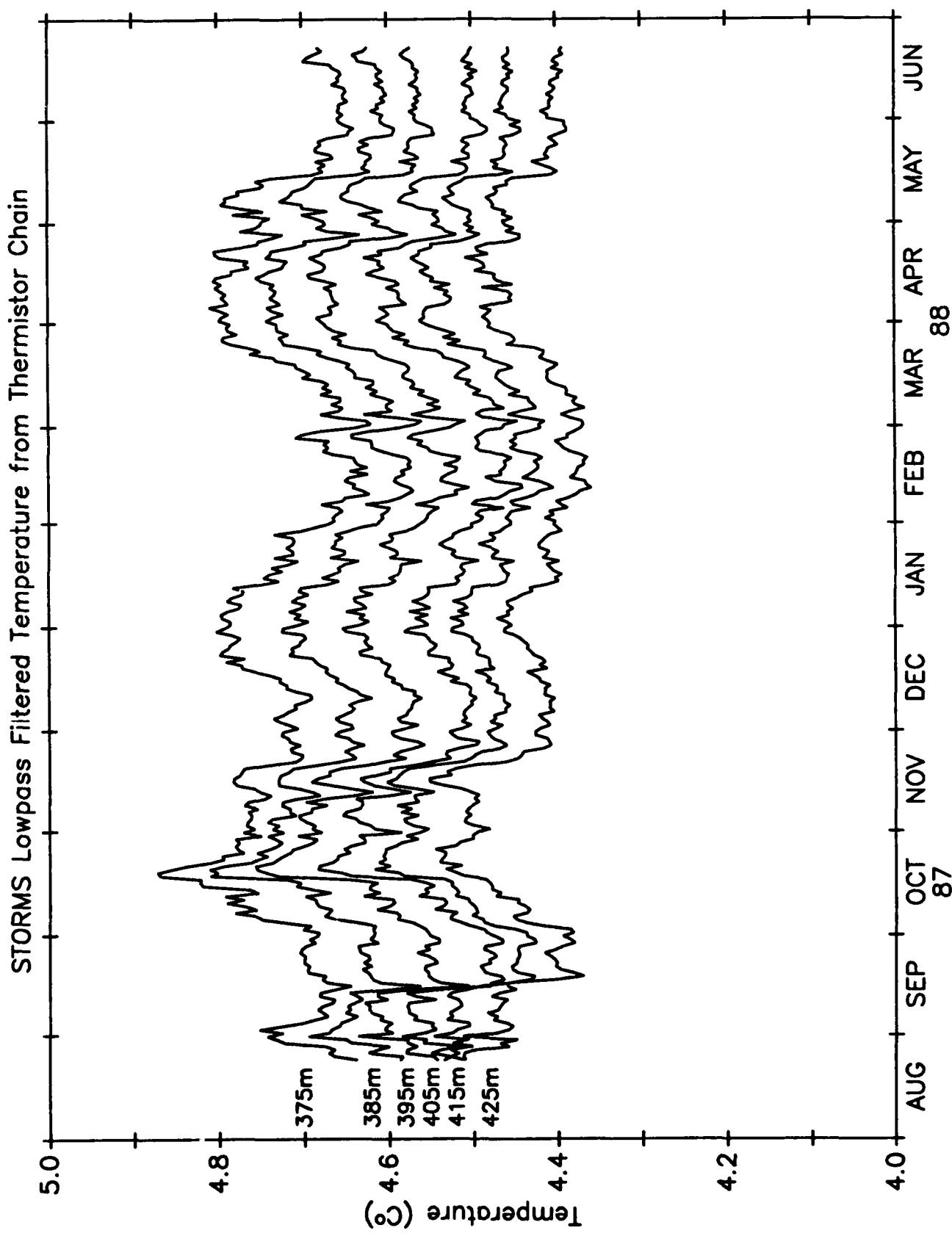
TIME SERIES OF TEMPERATURE: LOW-PASS FILTERED

The following four plots are observations from thermistor chains spanning depths 163–193 m, 206–236 m, 250–350 m, and 375–425 m. Data are low-pass filtered (40 hour half-power) and decimated to daily values.



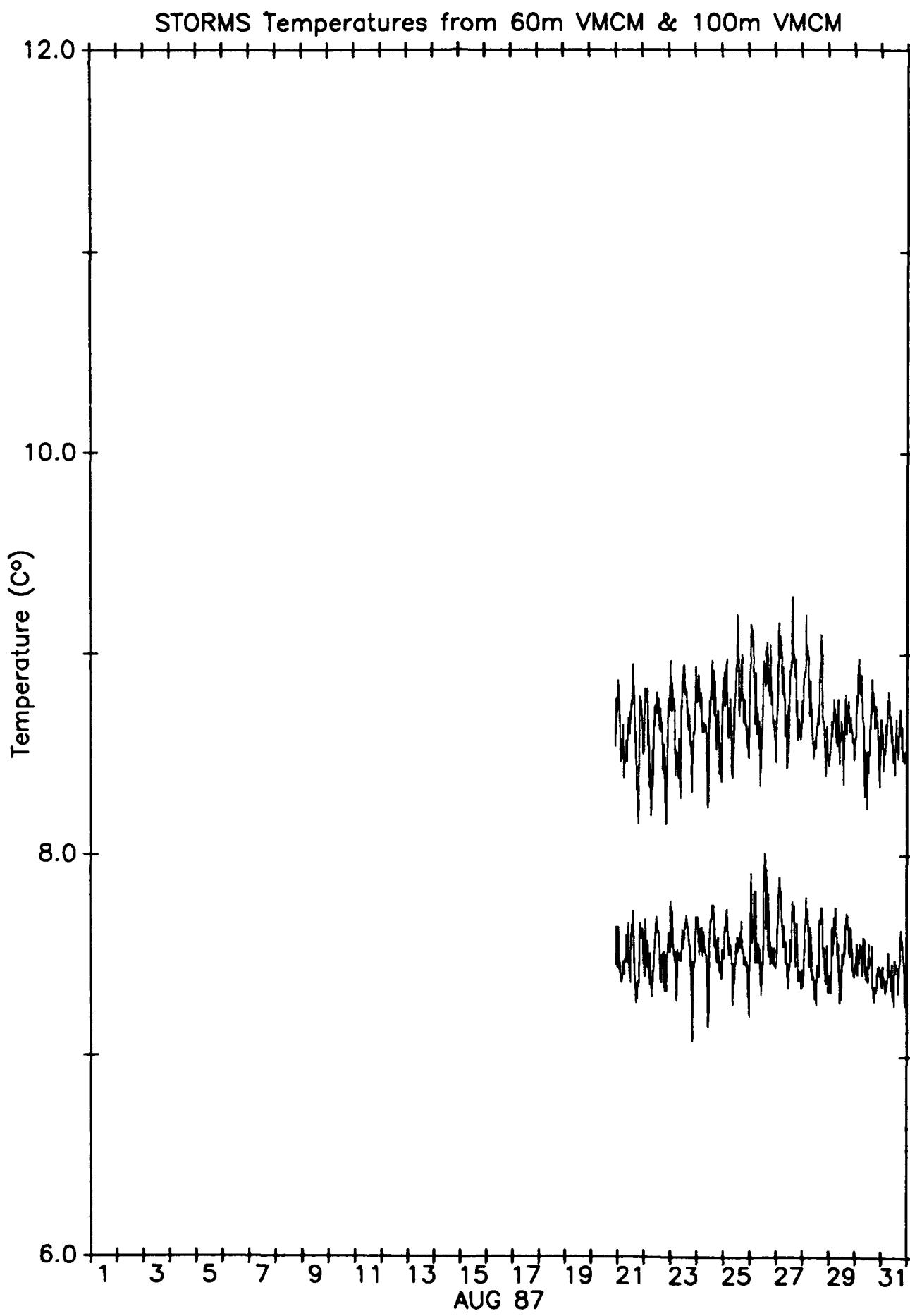




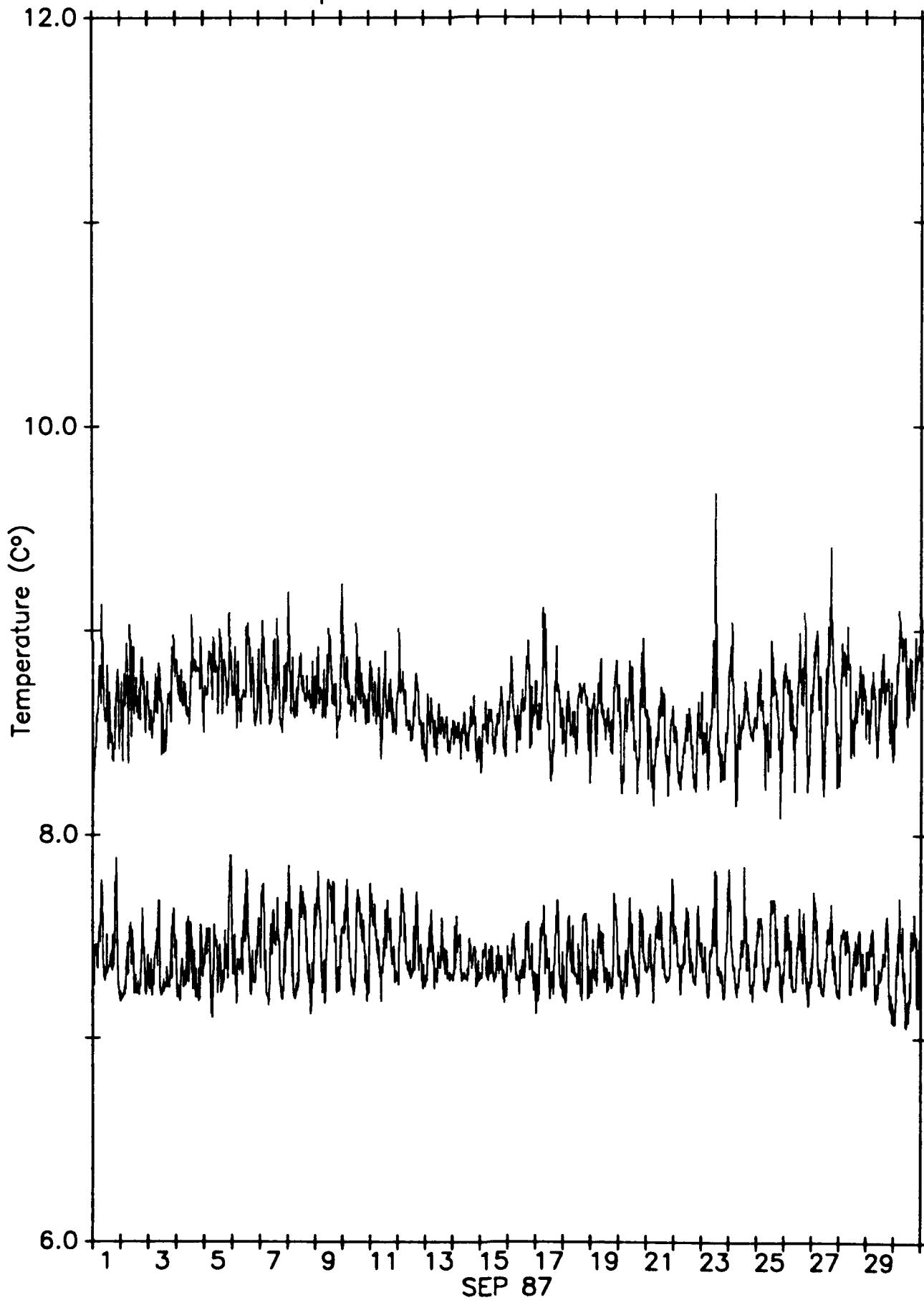


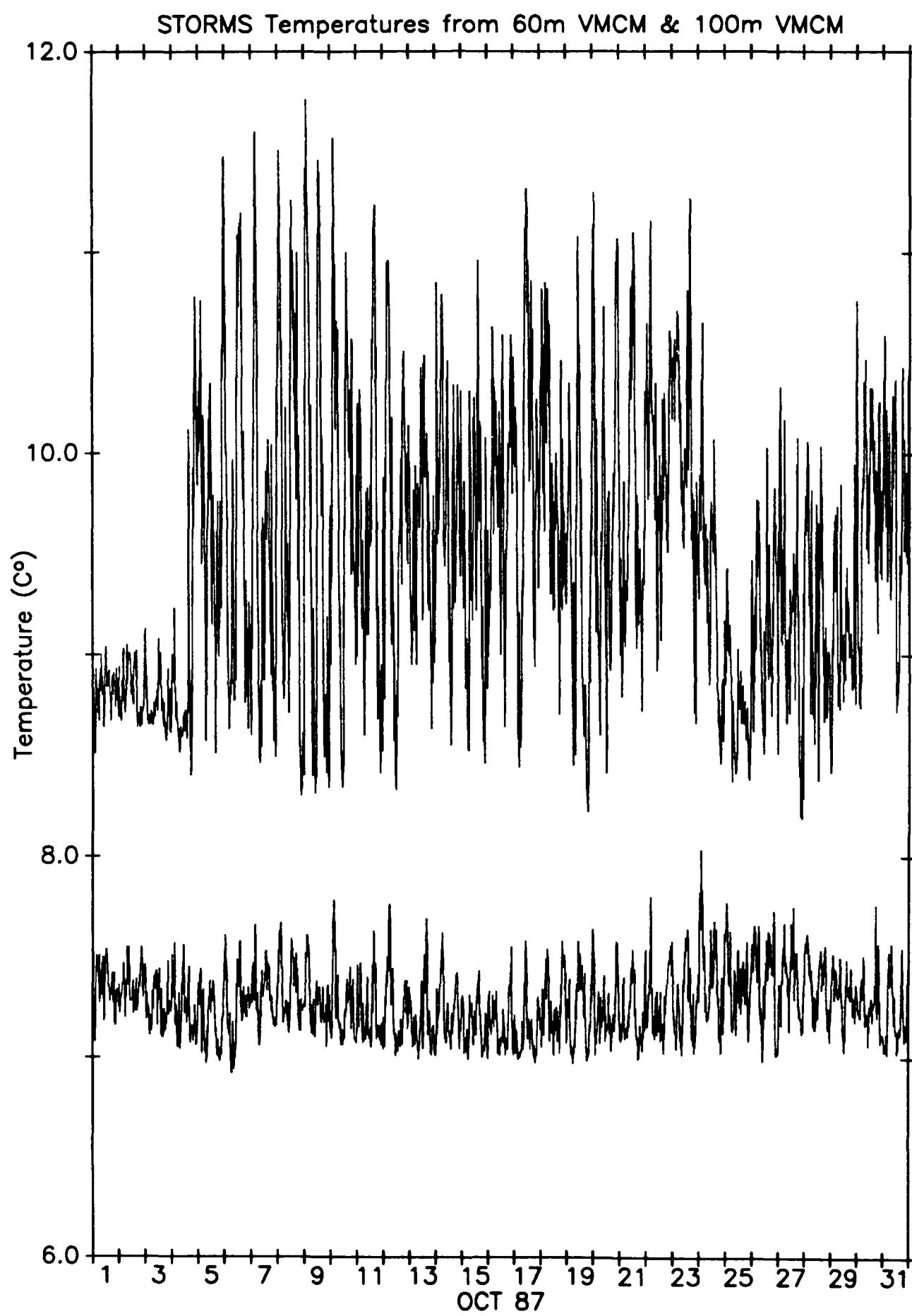
TIME SERIES OF TEMPERATURE: UNFILTERED

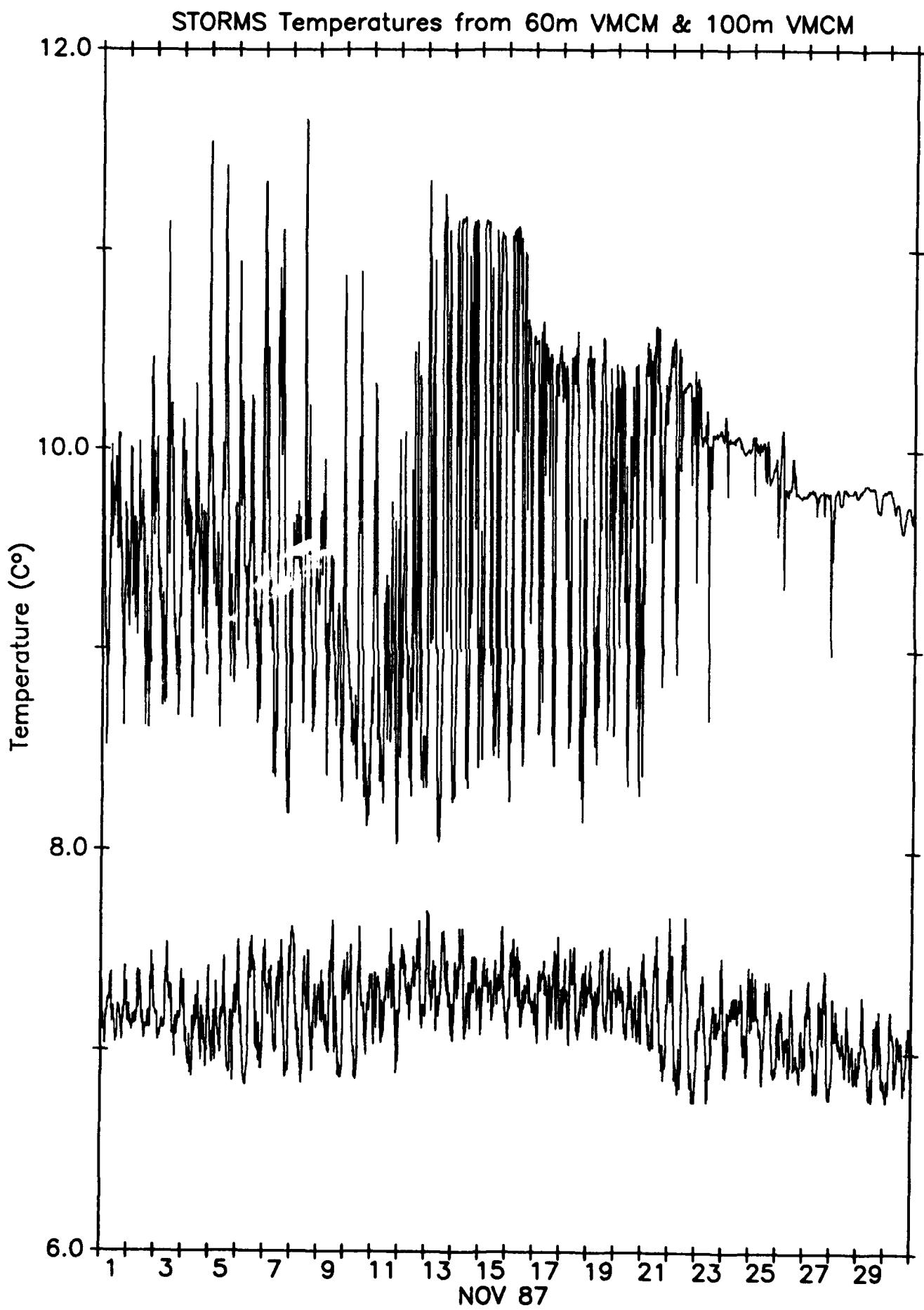
On the following 11 pages are observations from VMCMs at 60 and 100 m. One month is plotted per page; sampling interval is 15 minutes.

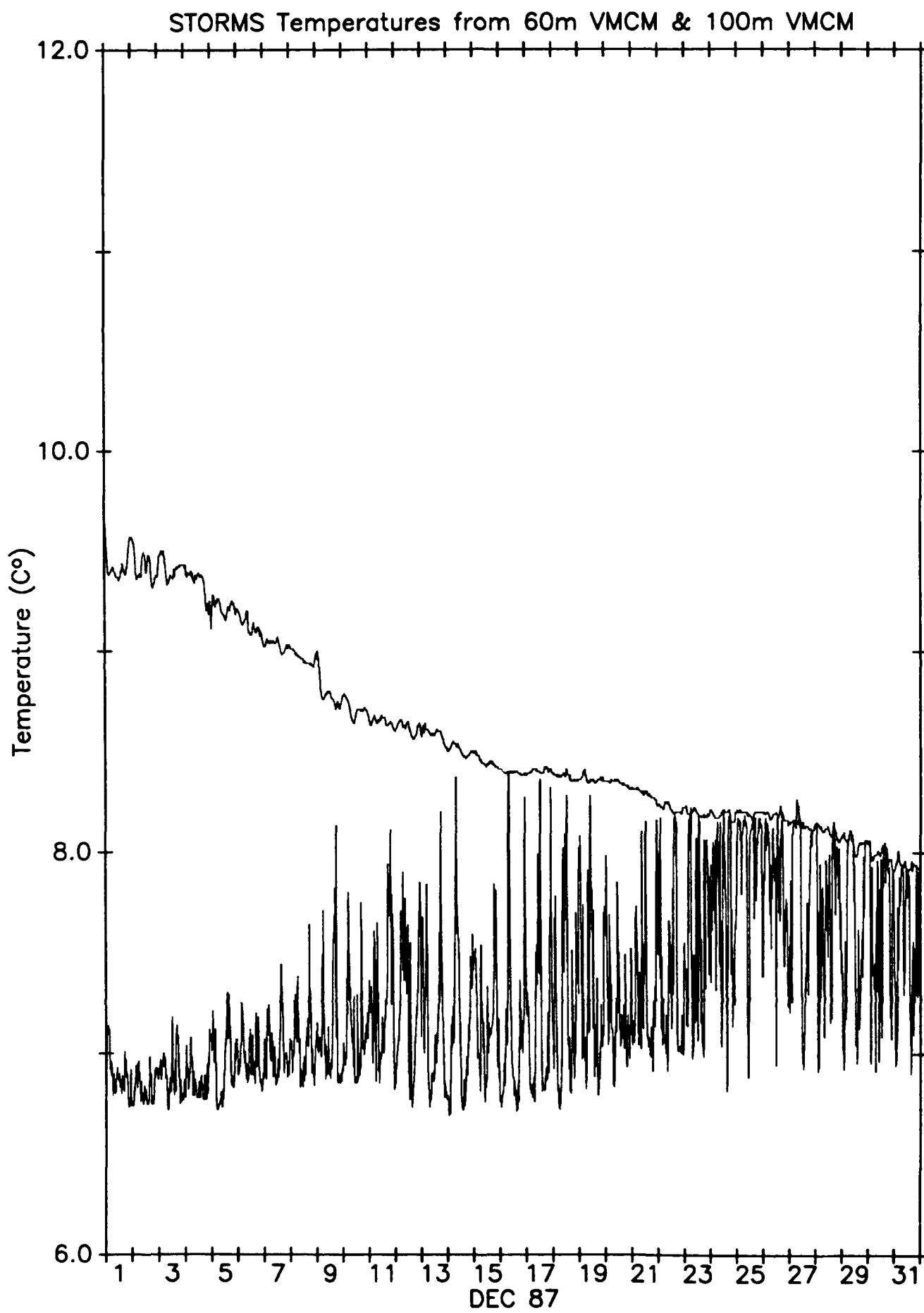


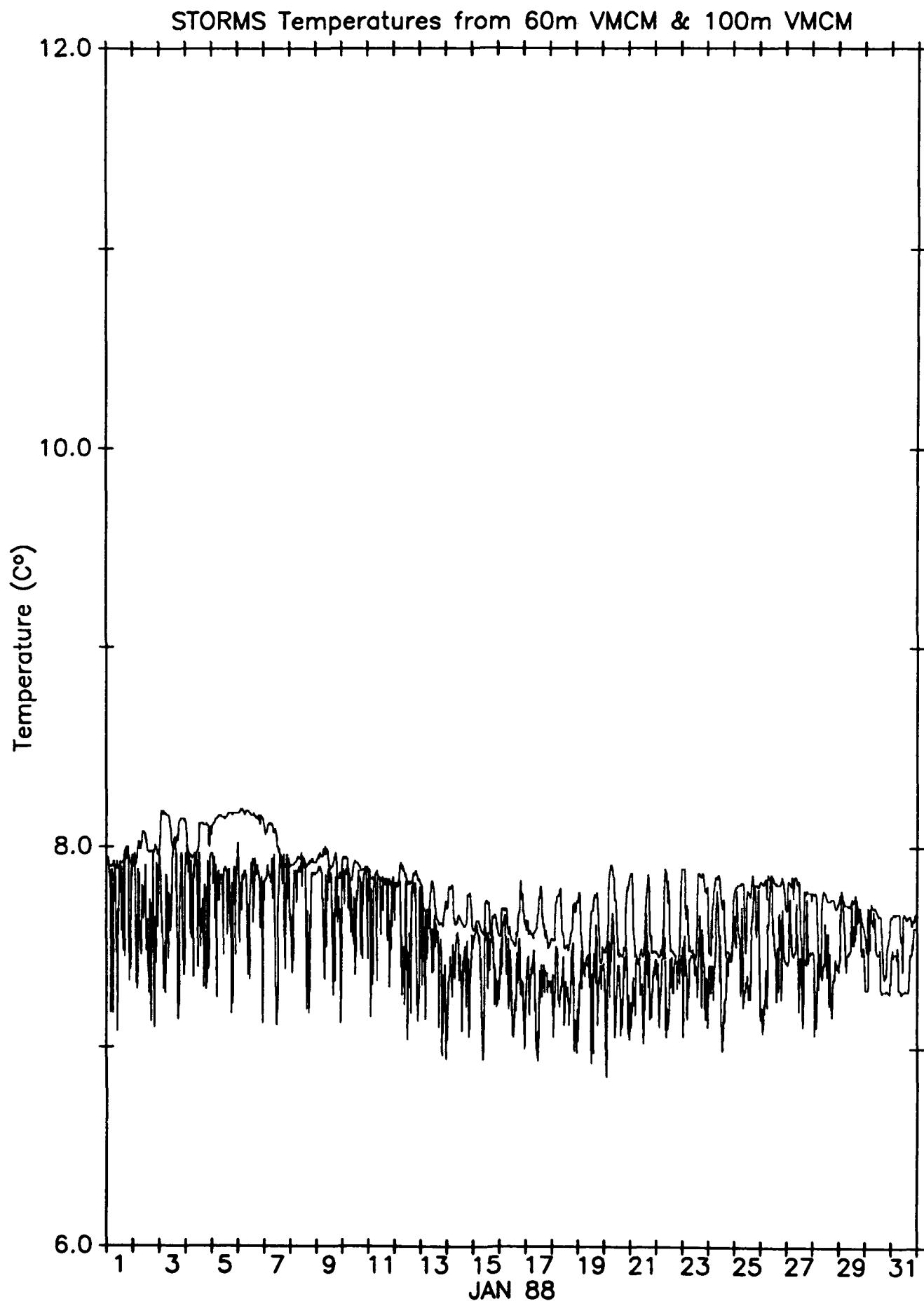
STORMS Temperatures from 60m VMCM & 100m VMCM

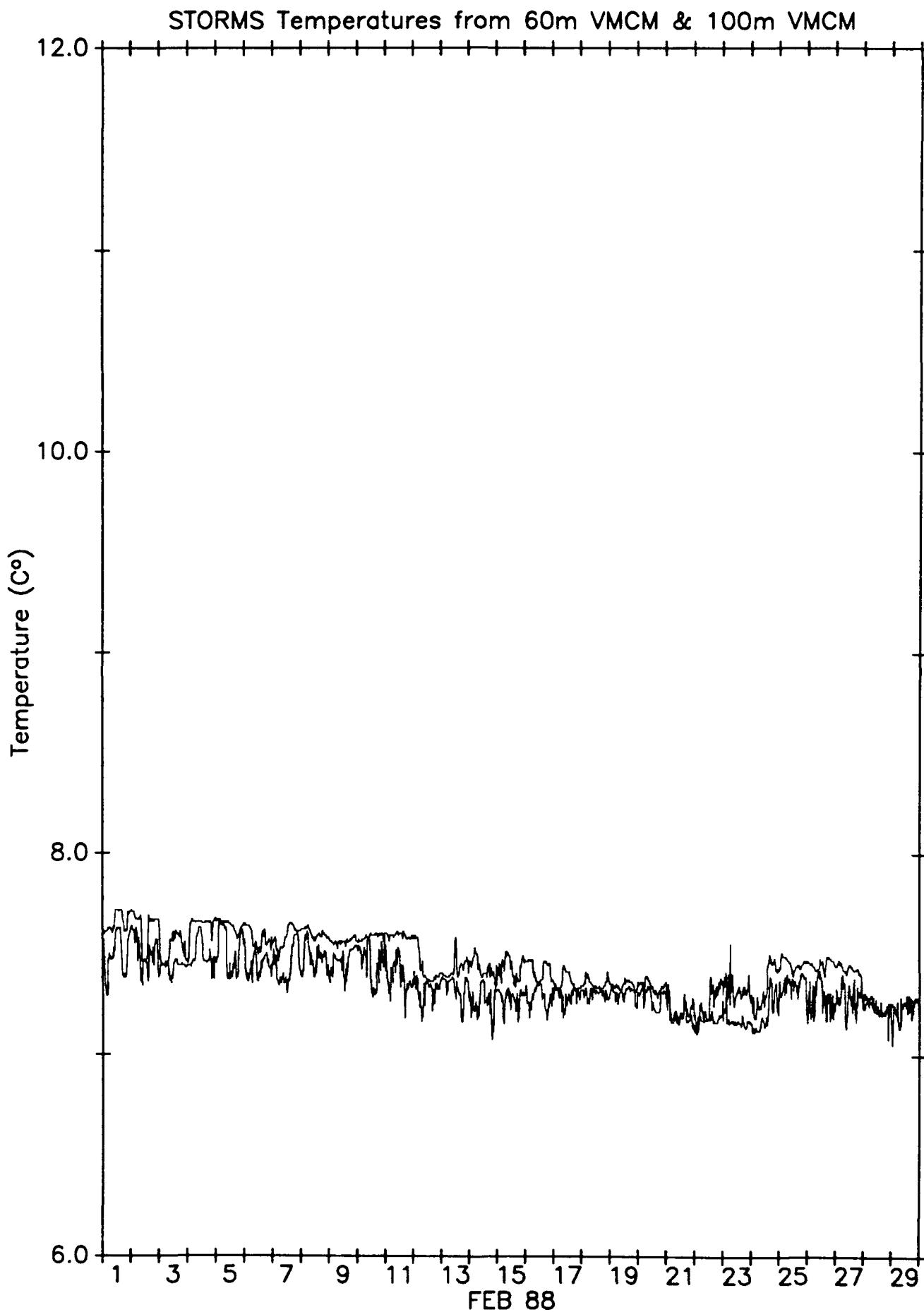


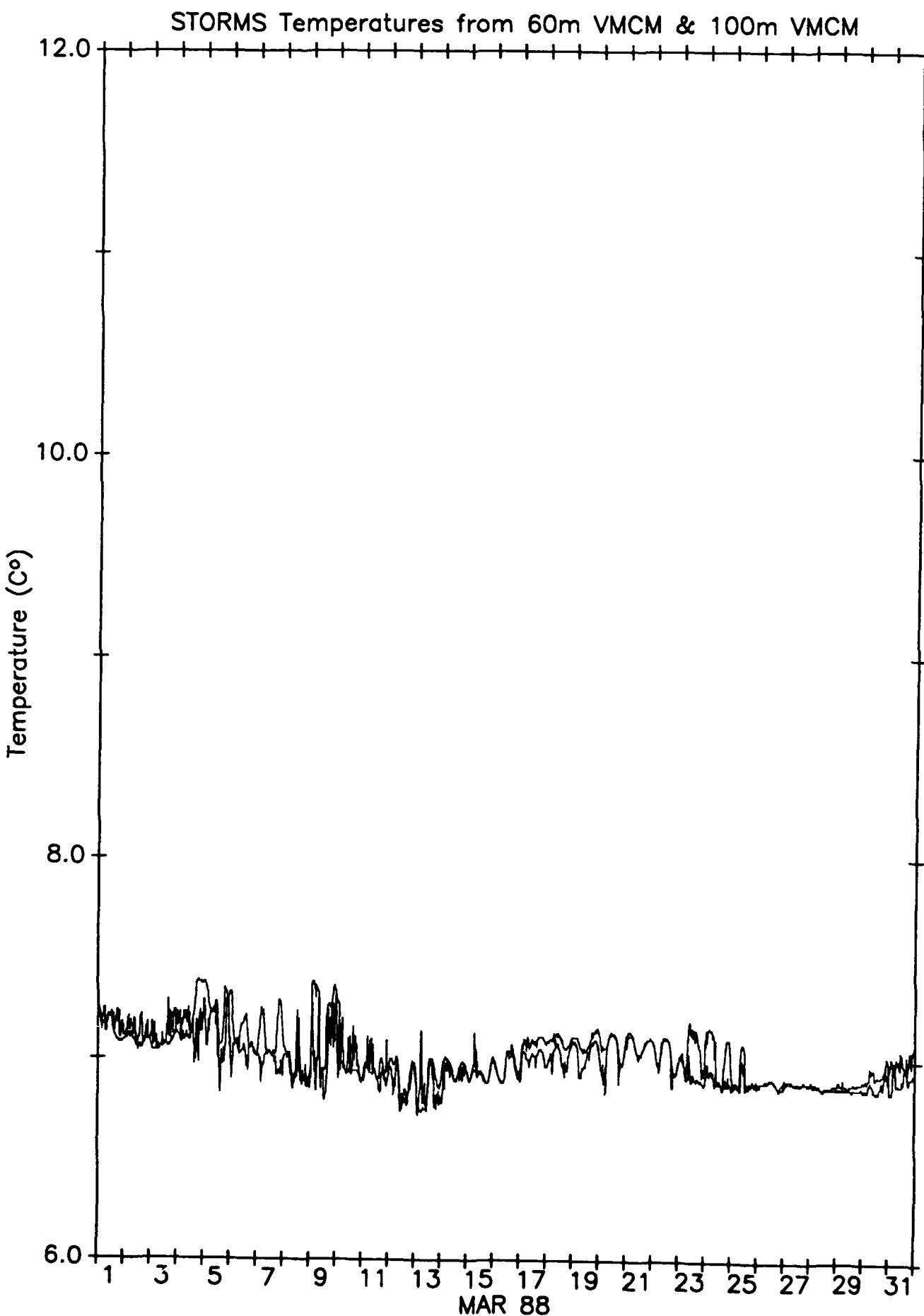


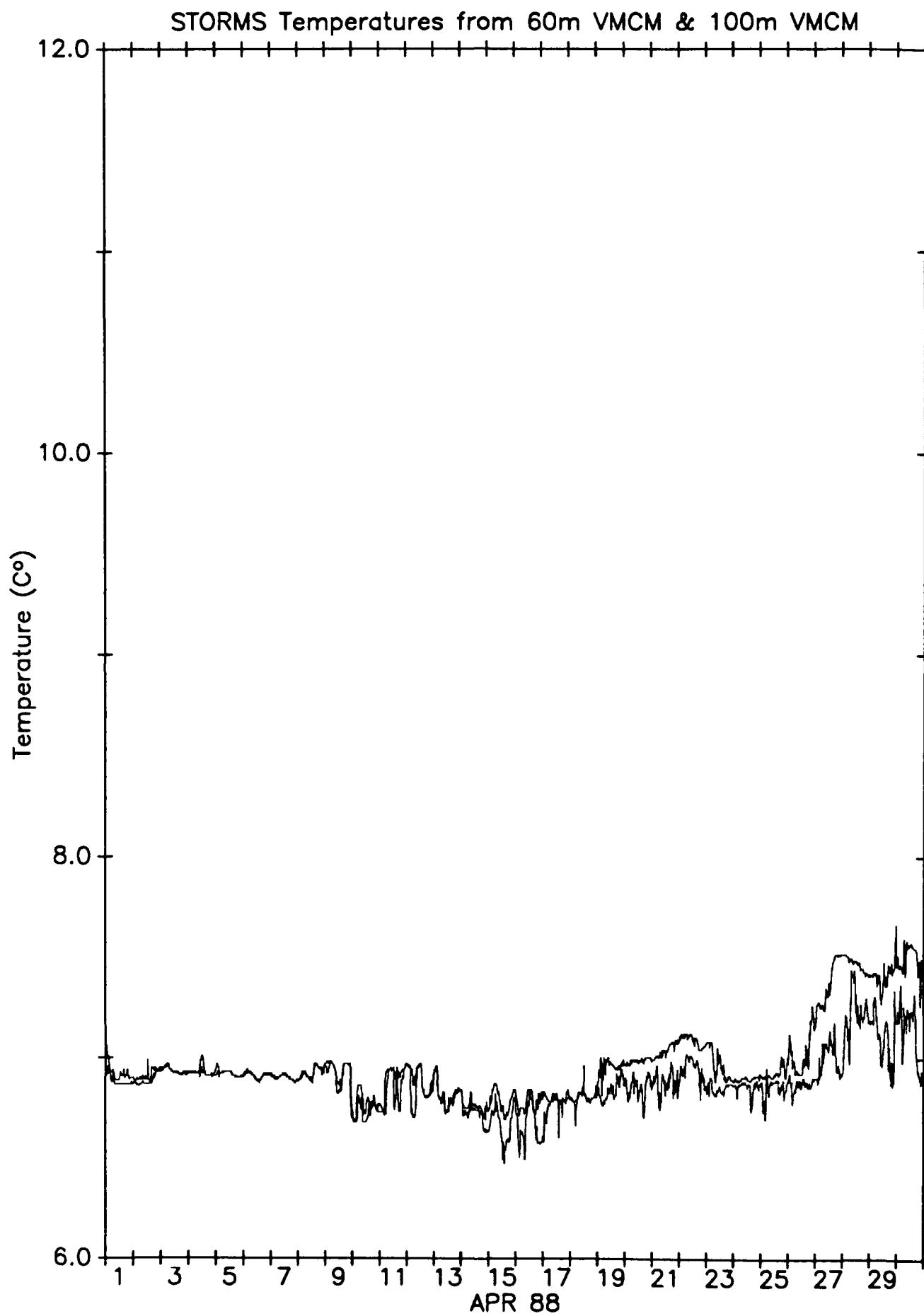


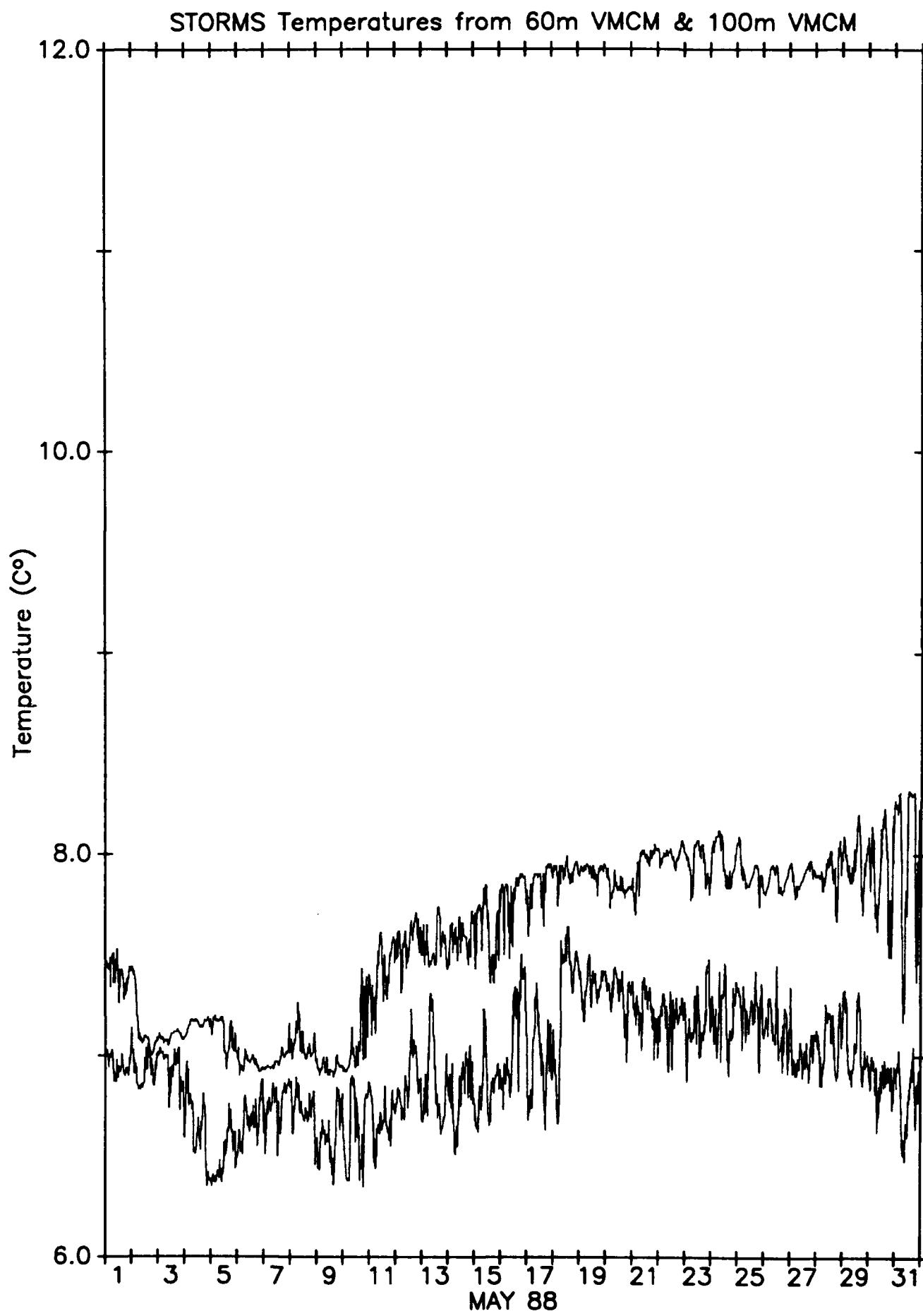


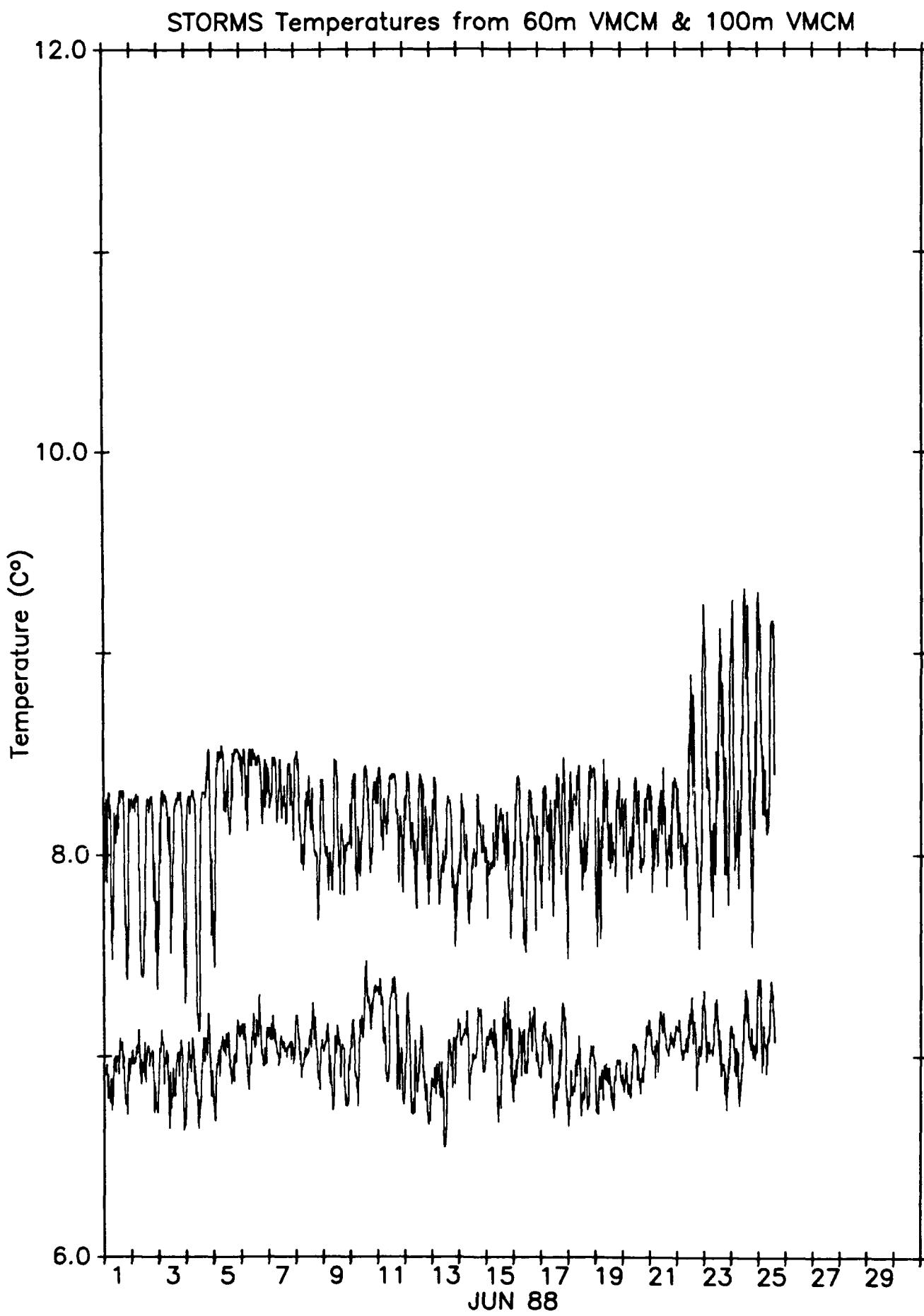






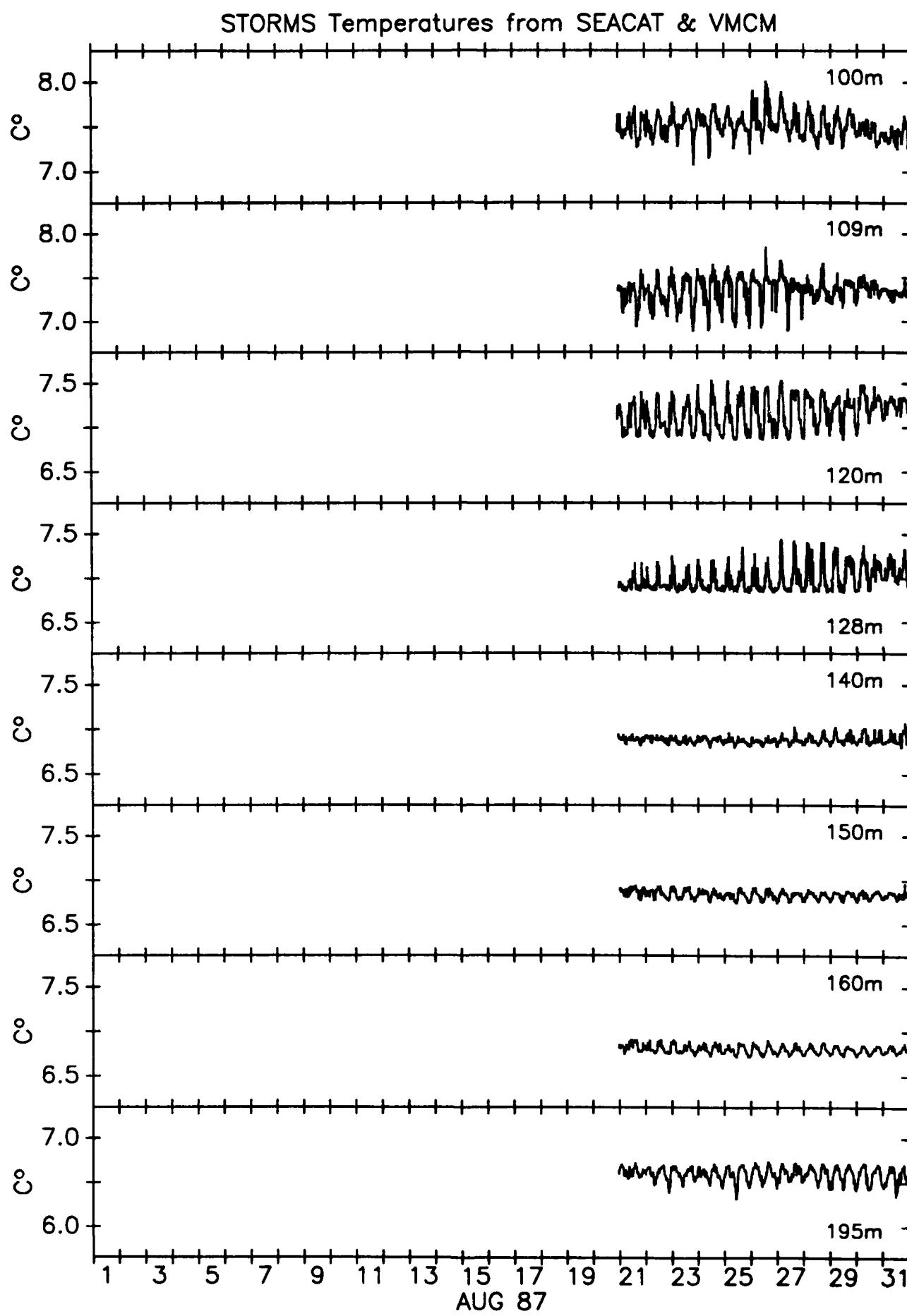


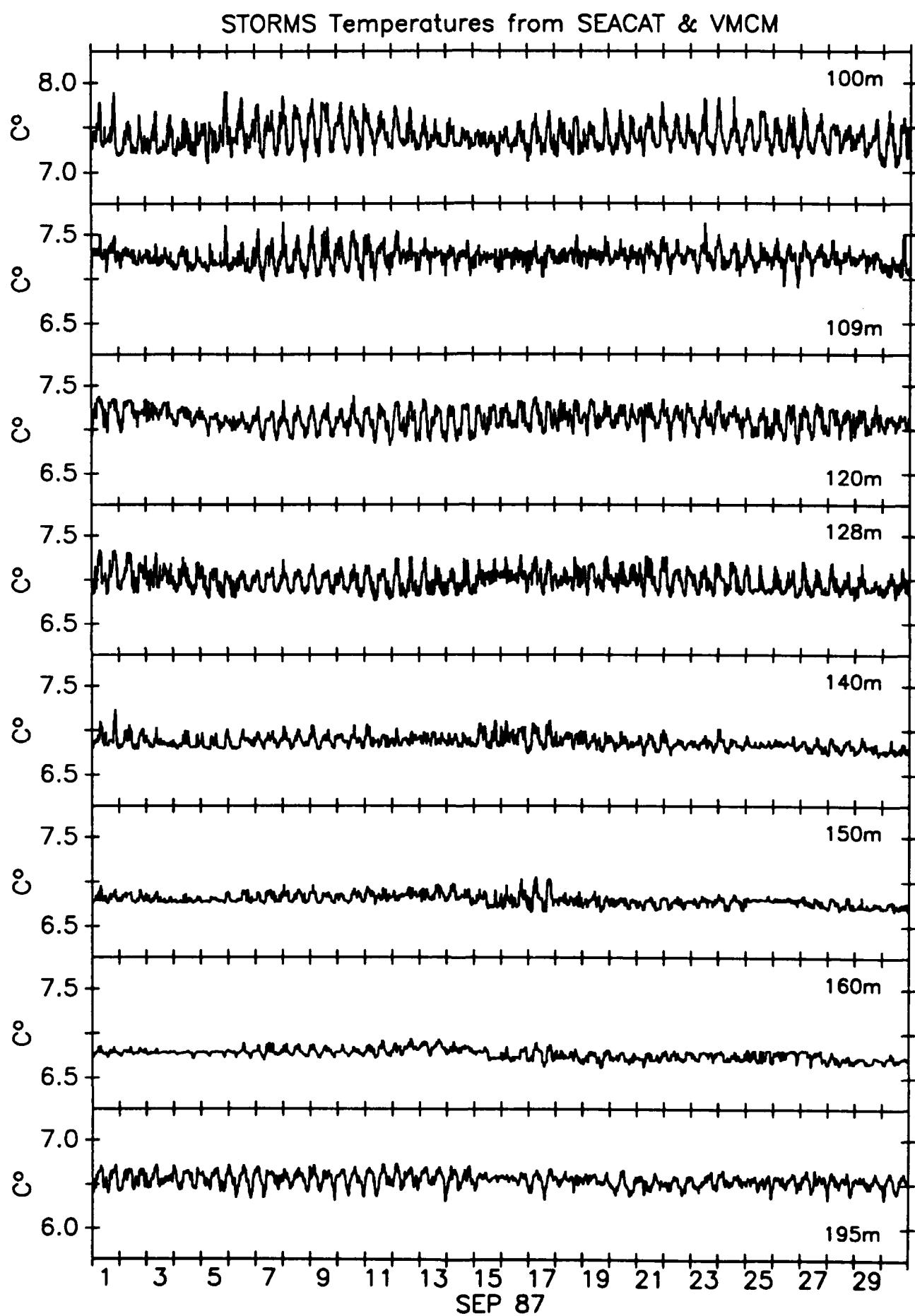




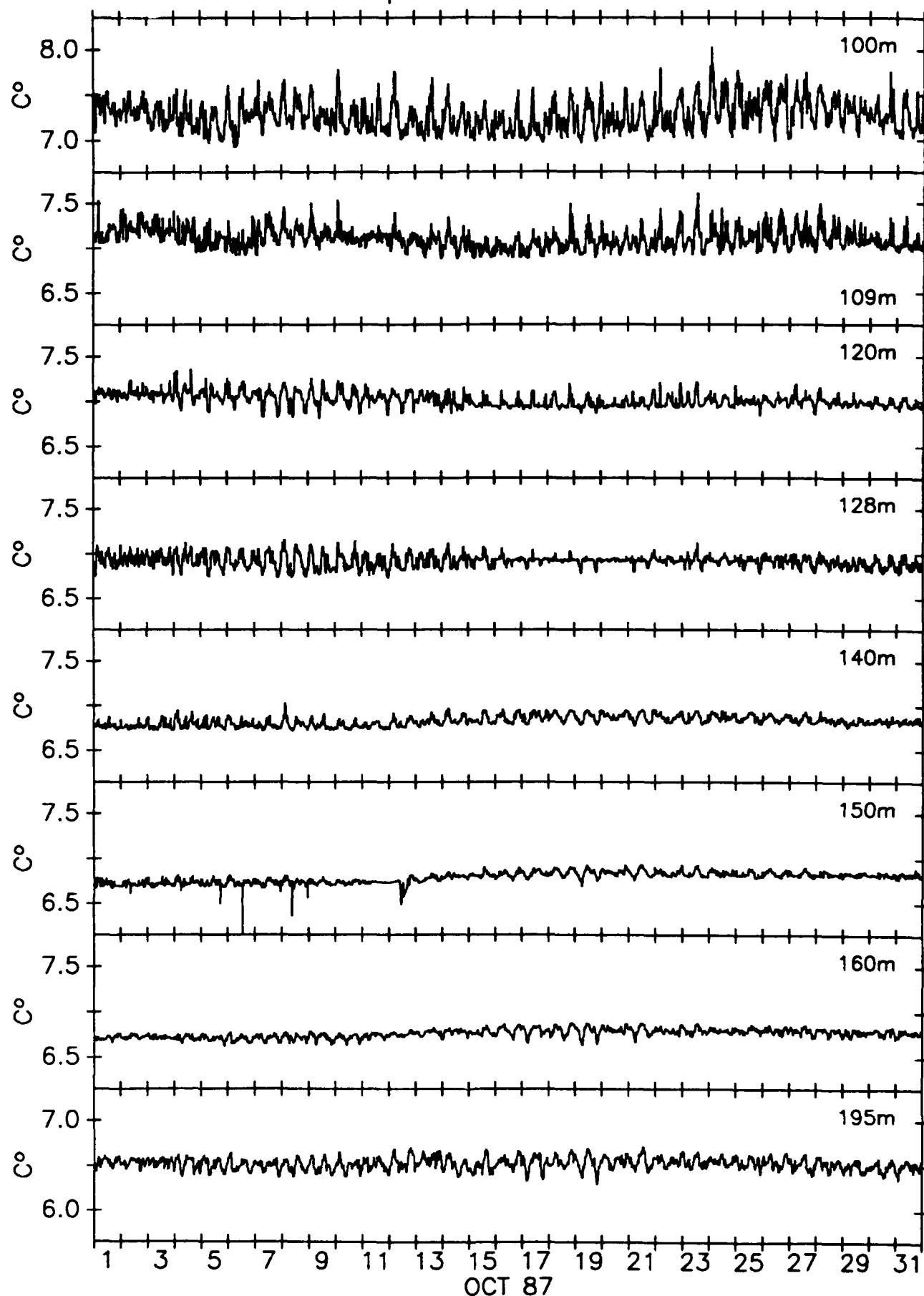
TIME SERIES OF TEMPERATURE: UNFILTERED

On the following 11 pages are observations from 100 to 195 m from VMCMs at 100, 120, 140, 160 and 195 m and from Seacats at 109, 128 and 150 m. One month is plotted per page. Sampling interval for VMCMs is 15 minutes and for the Seacats is 6 minutes before 3/4/88 and 12 minutes after.

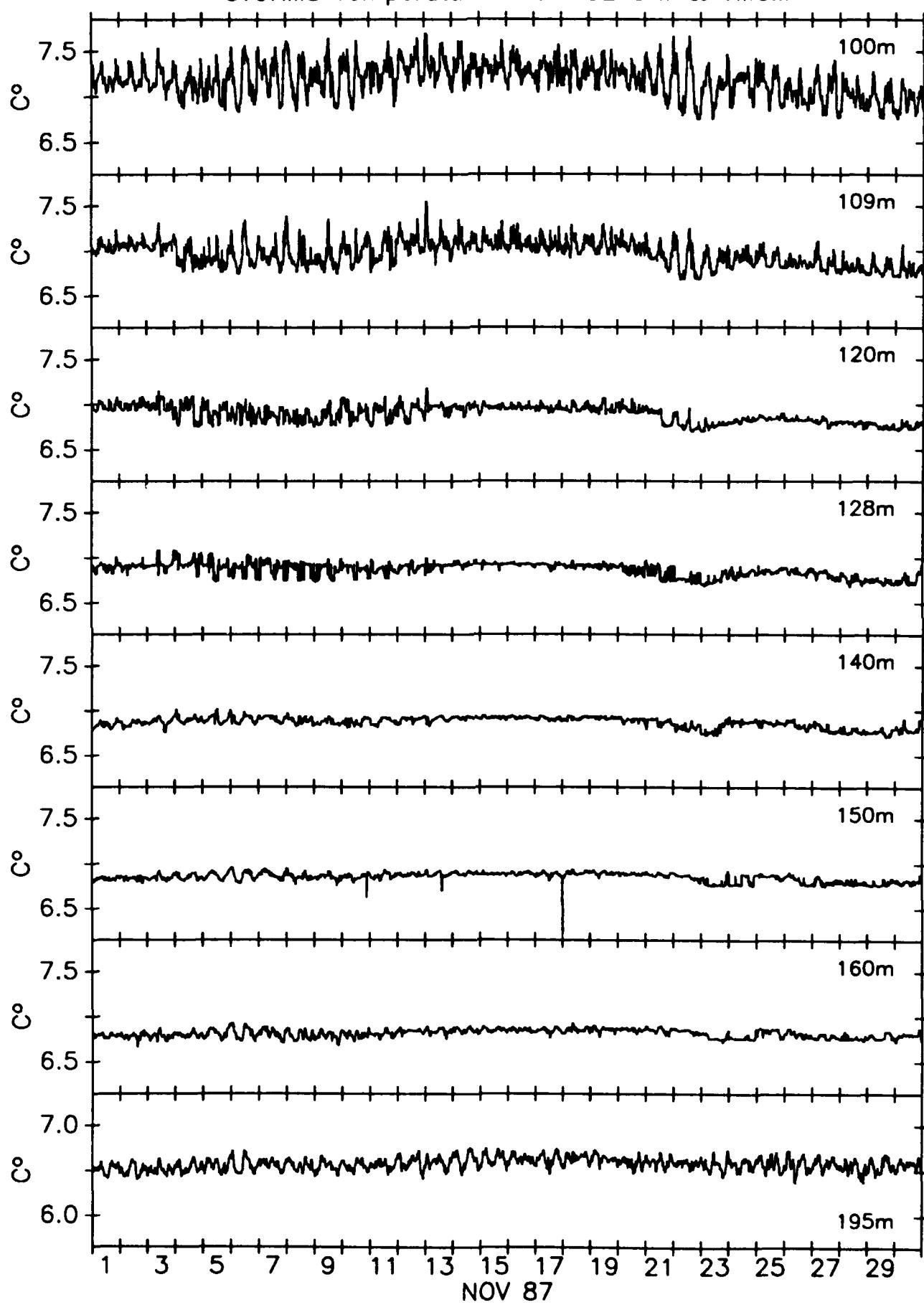


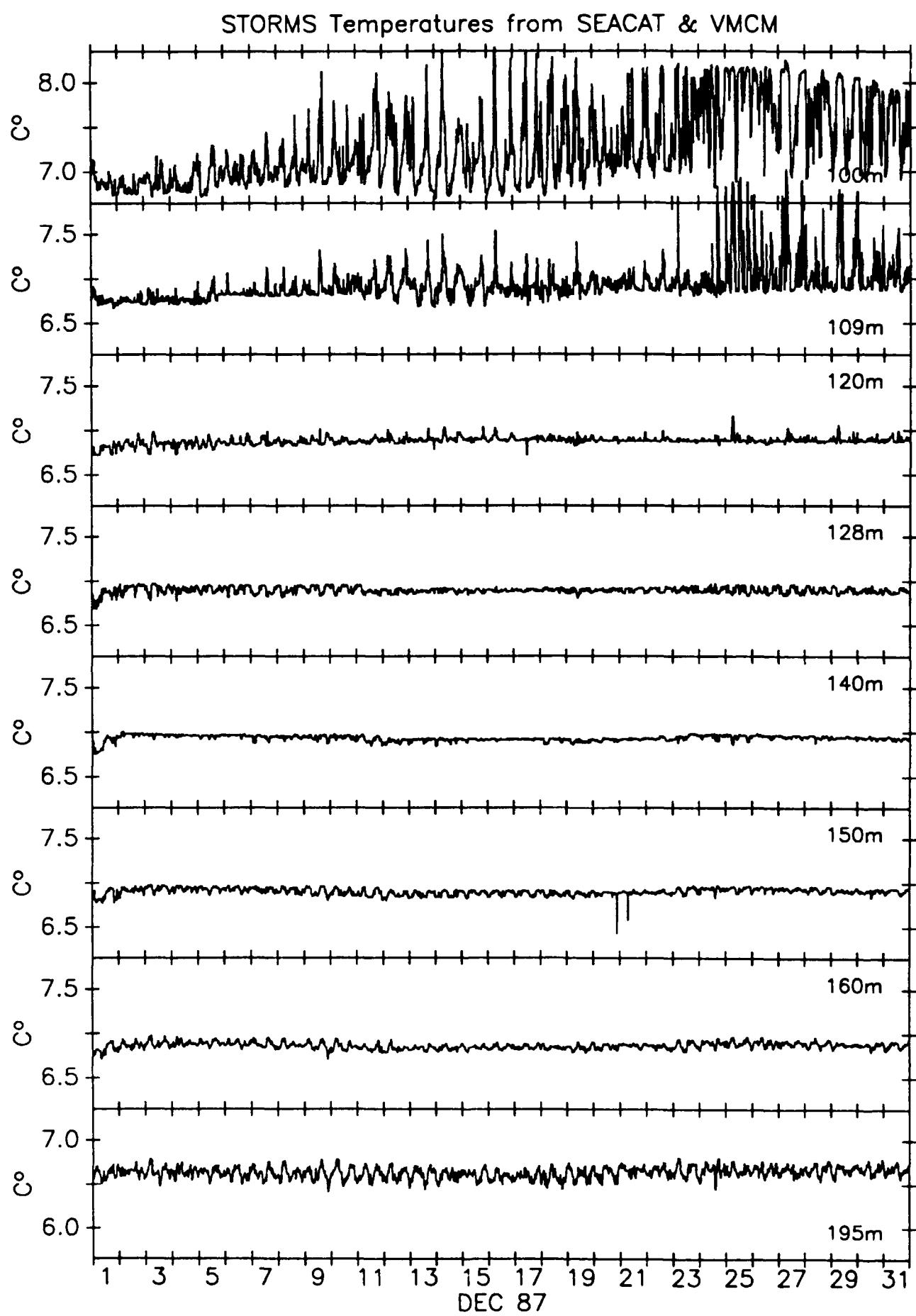


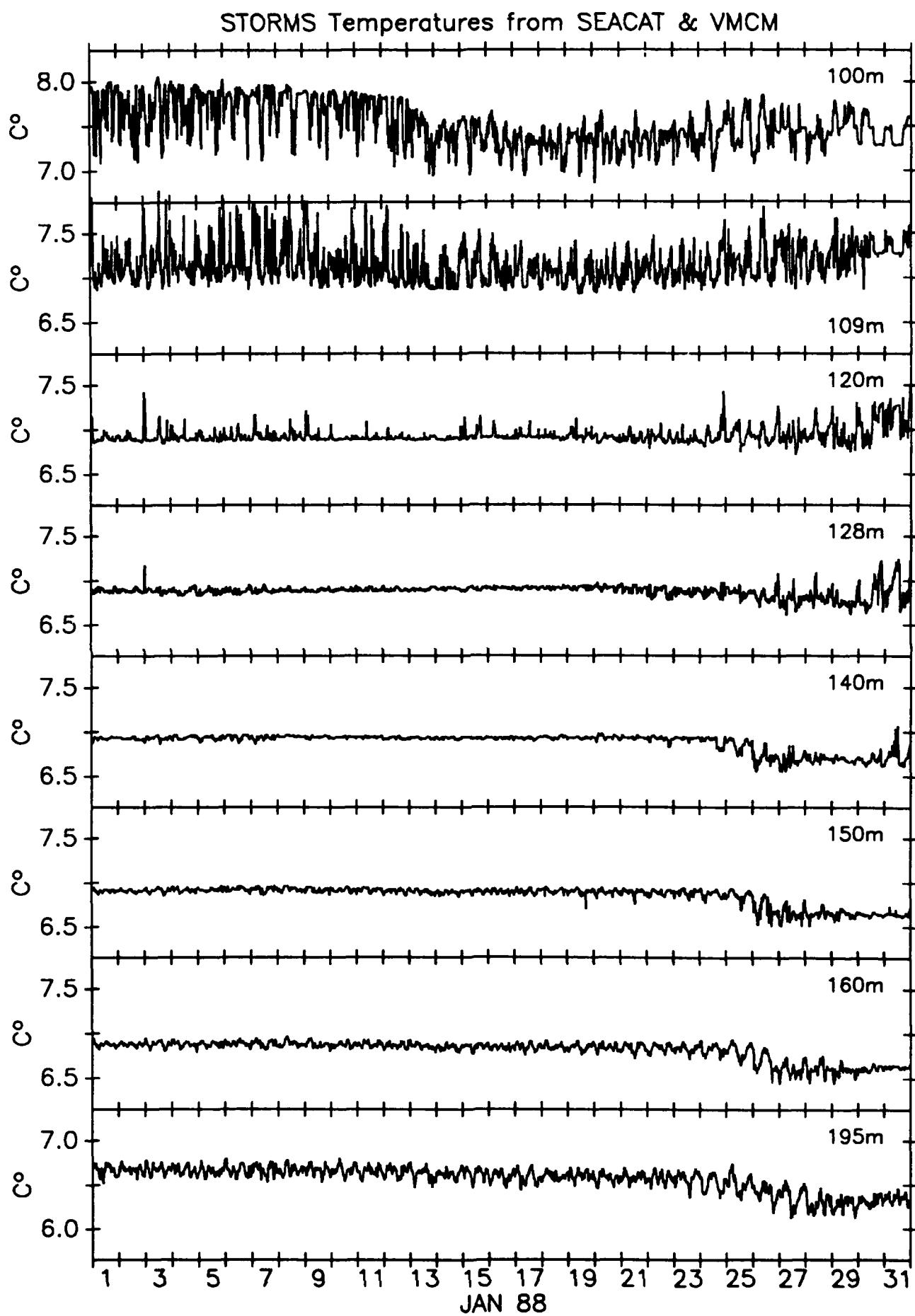
STORMS Temperatures from SEACAT & VMCM



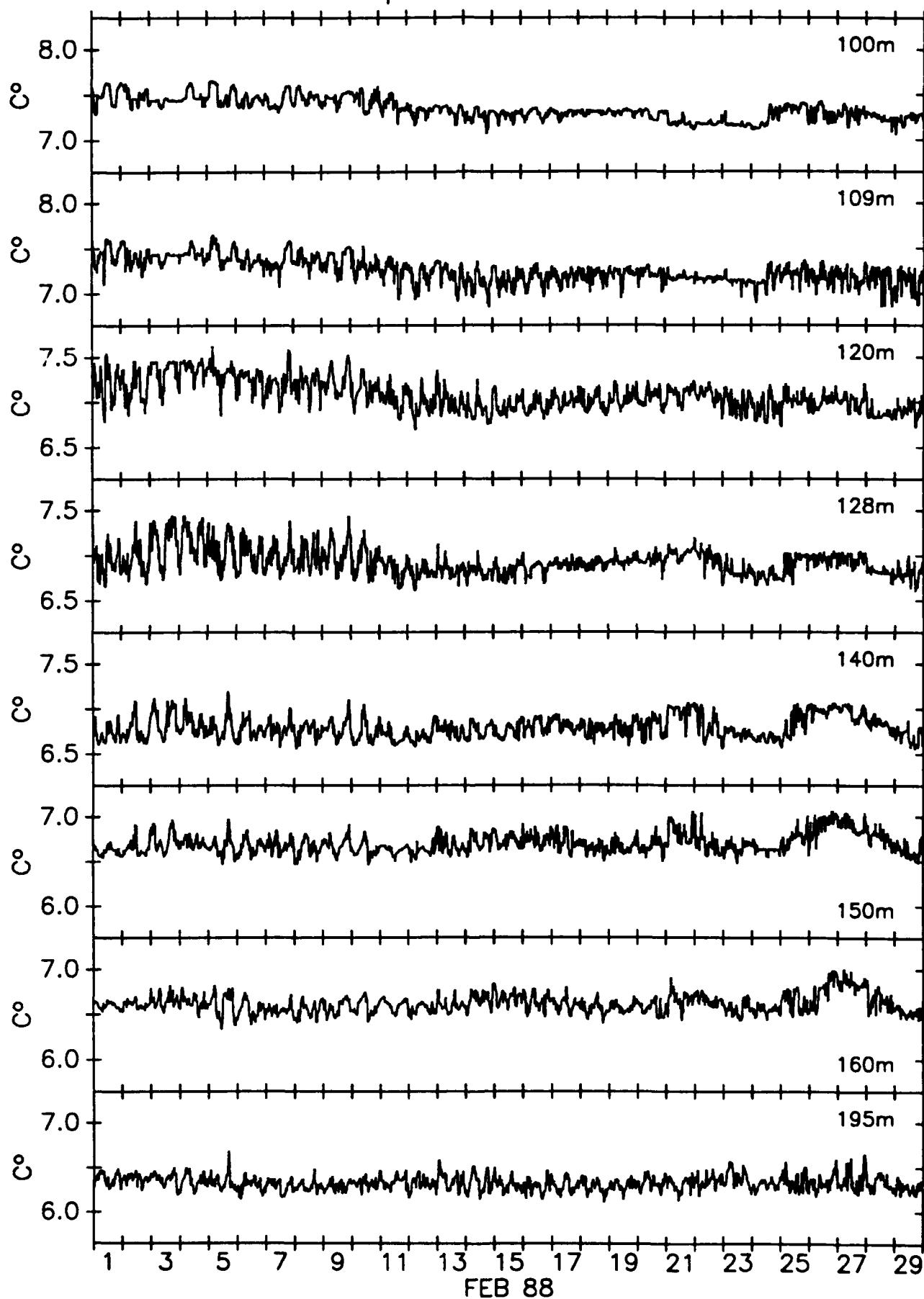
STORMS Temperatures from SEACAT & VMC



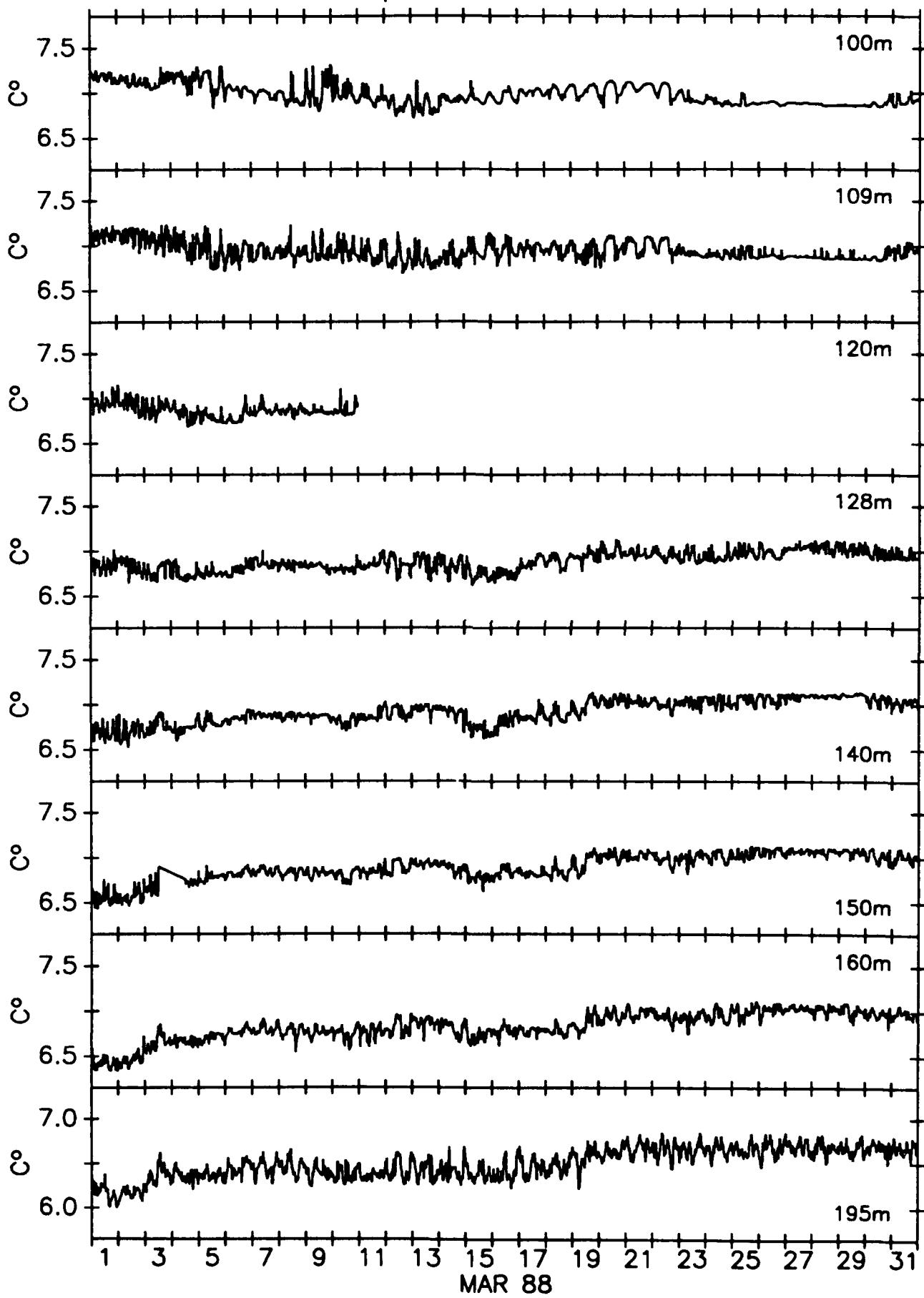




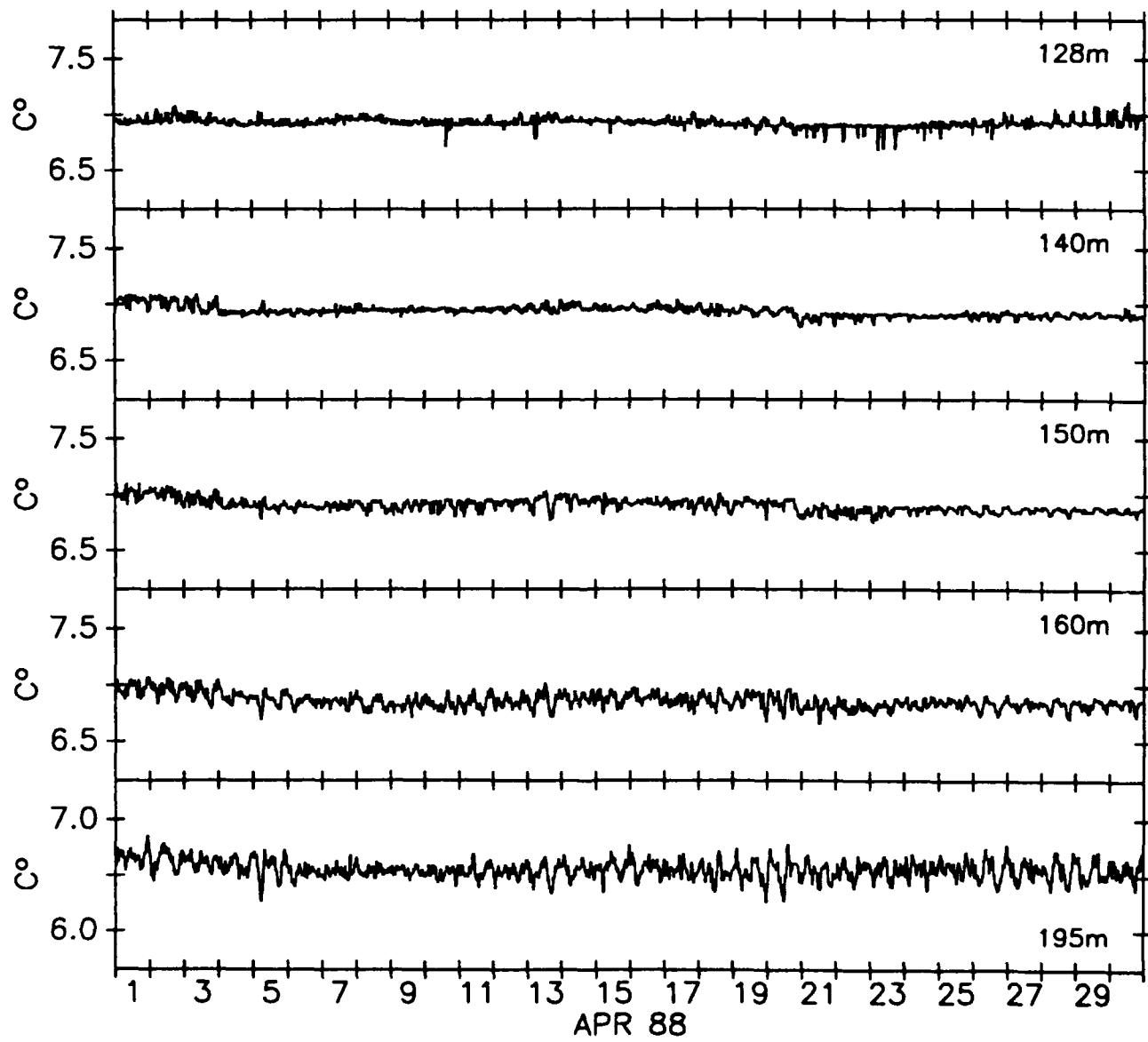
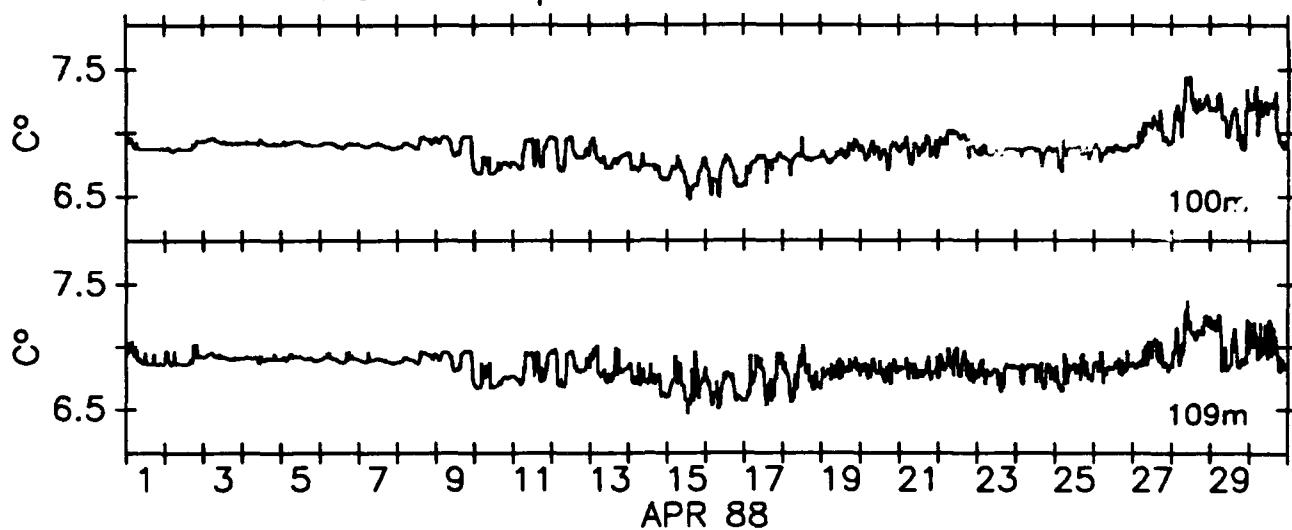
STORMS Temperatures from SEACAT & VMCM



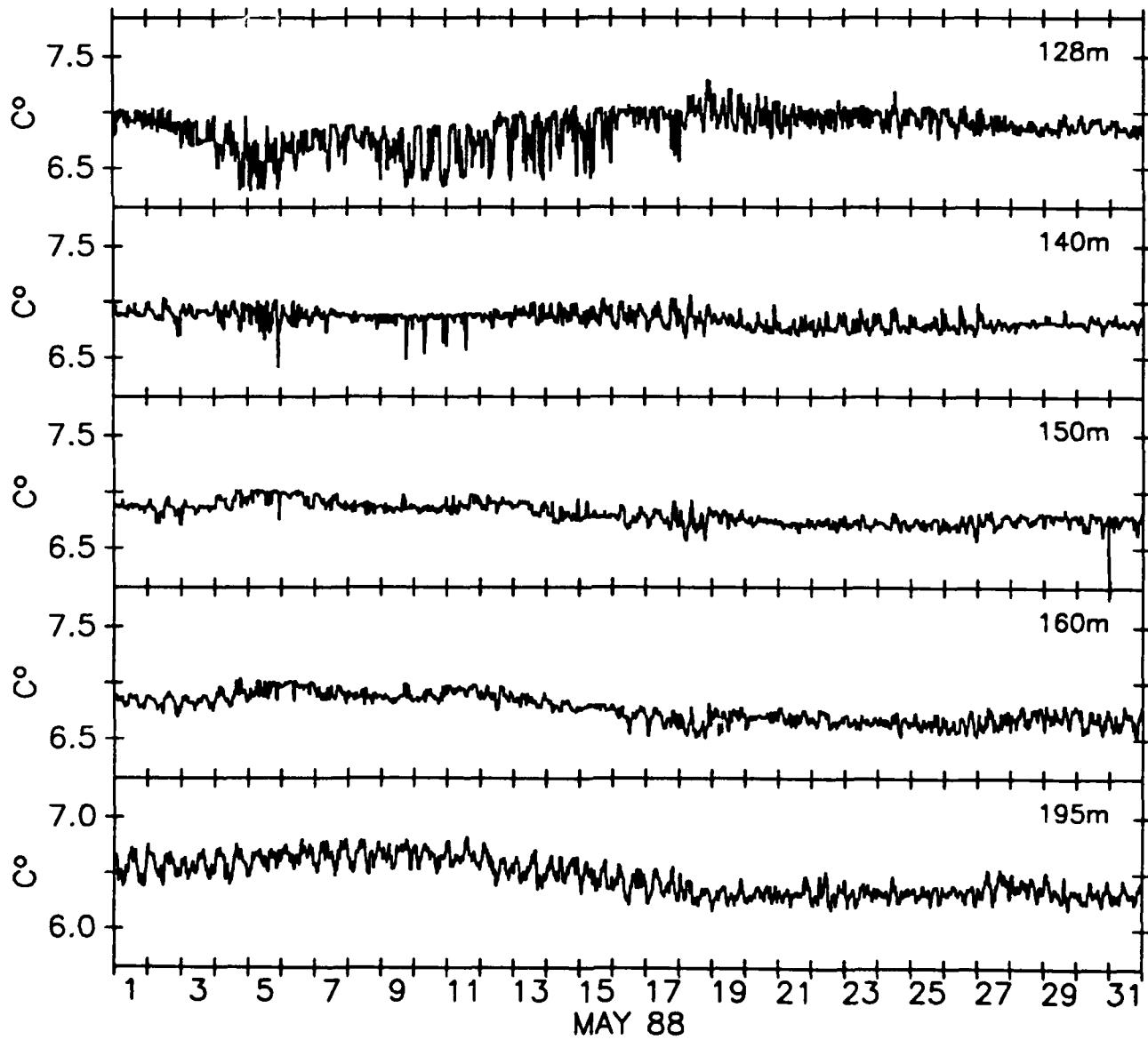
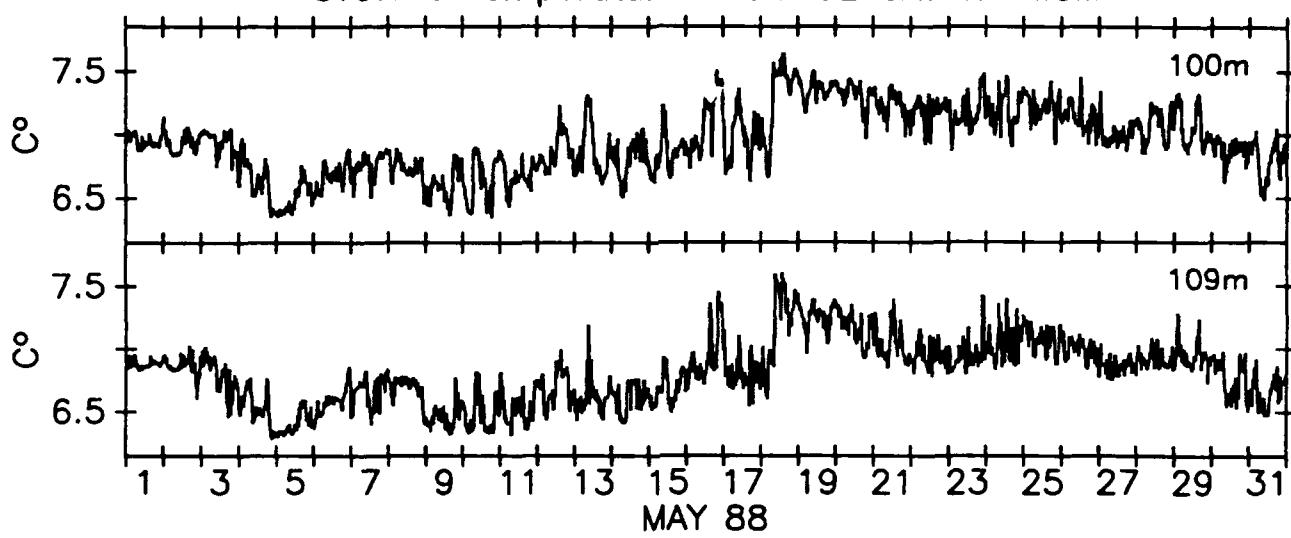
STORMS Temperatures from SEACAT & VMCM



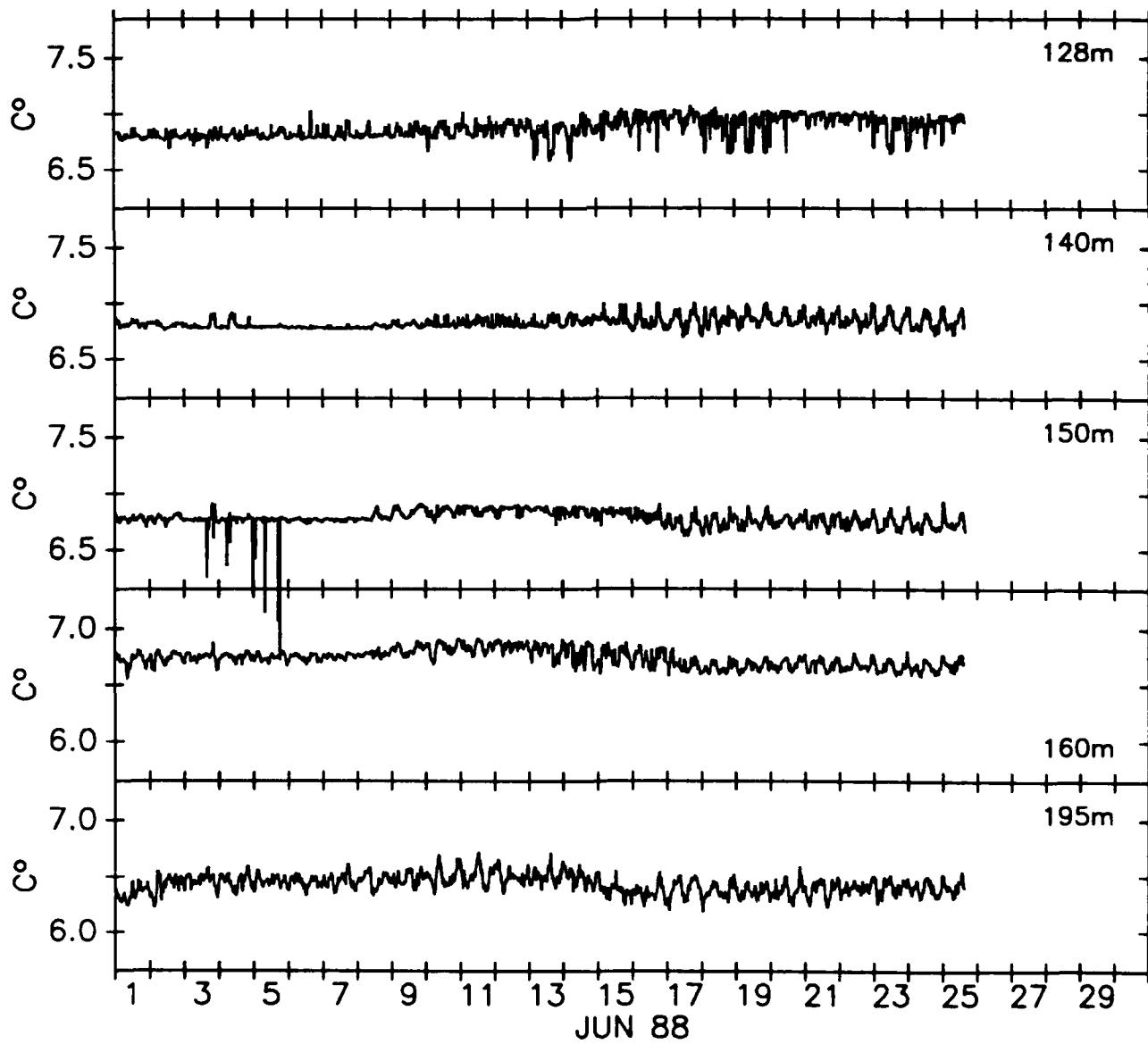
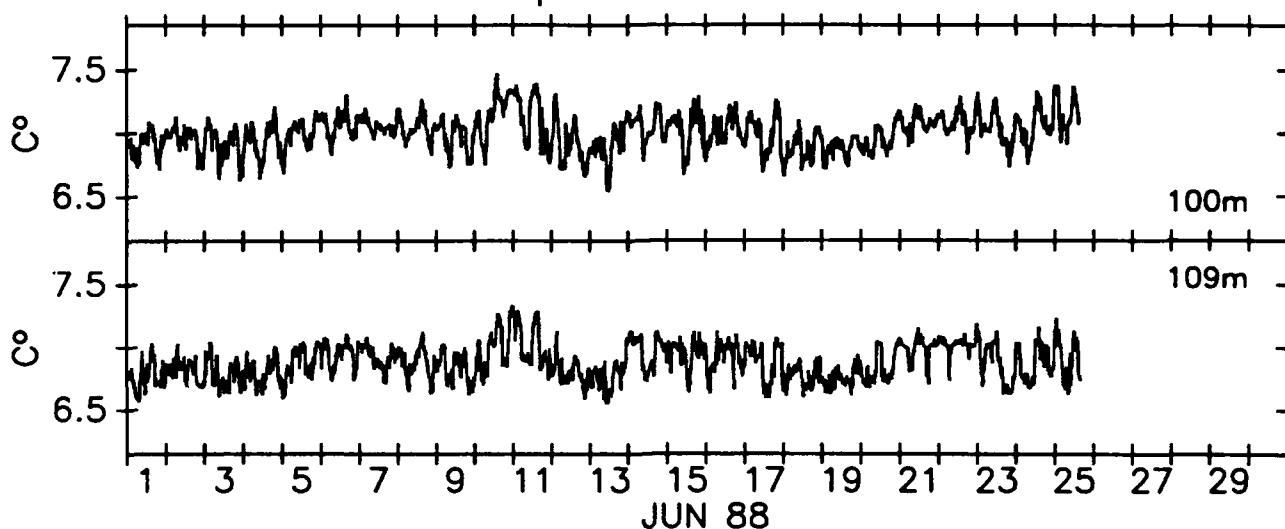
STORMS Temperatures from SEACAT & VMCM



STORMS Temperatures from SEACAT & VMCM

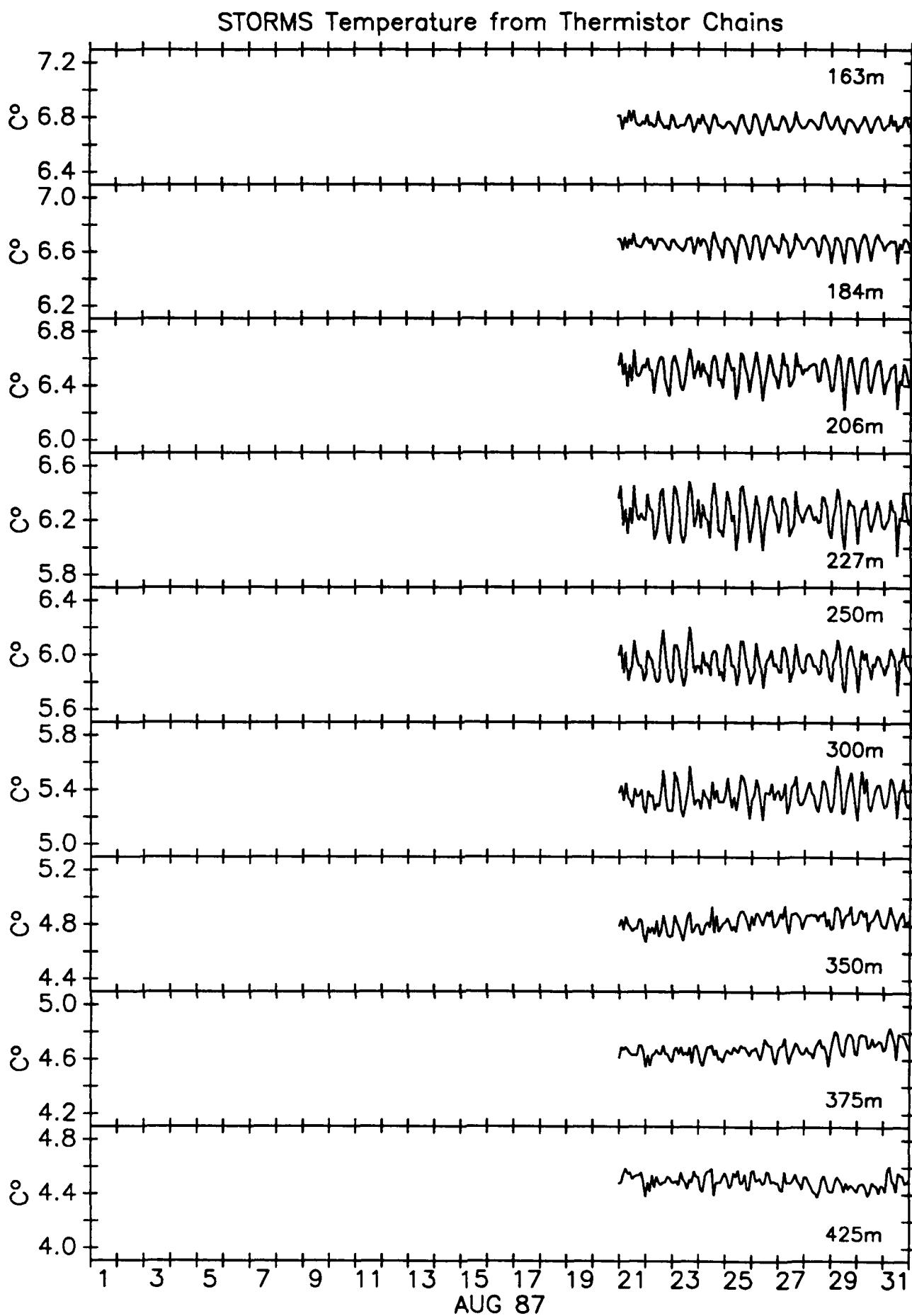


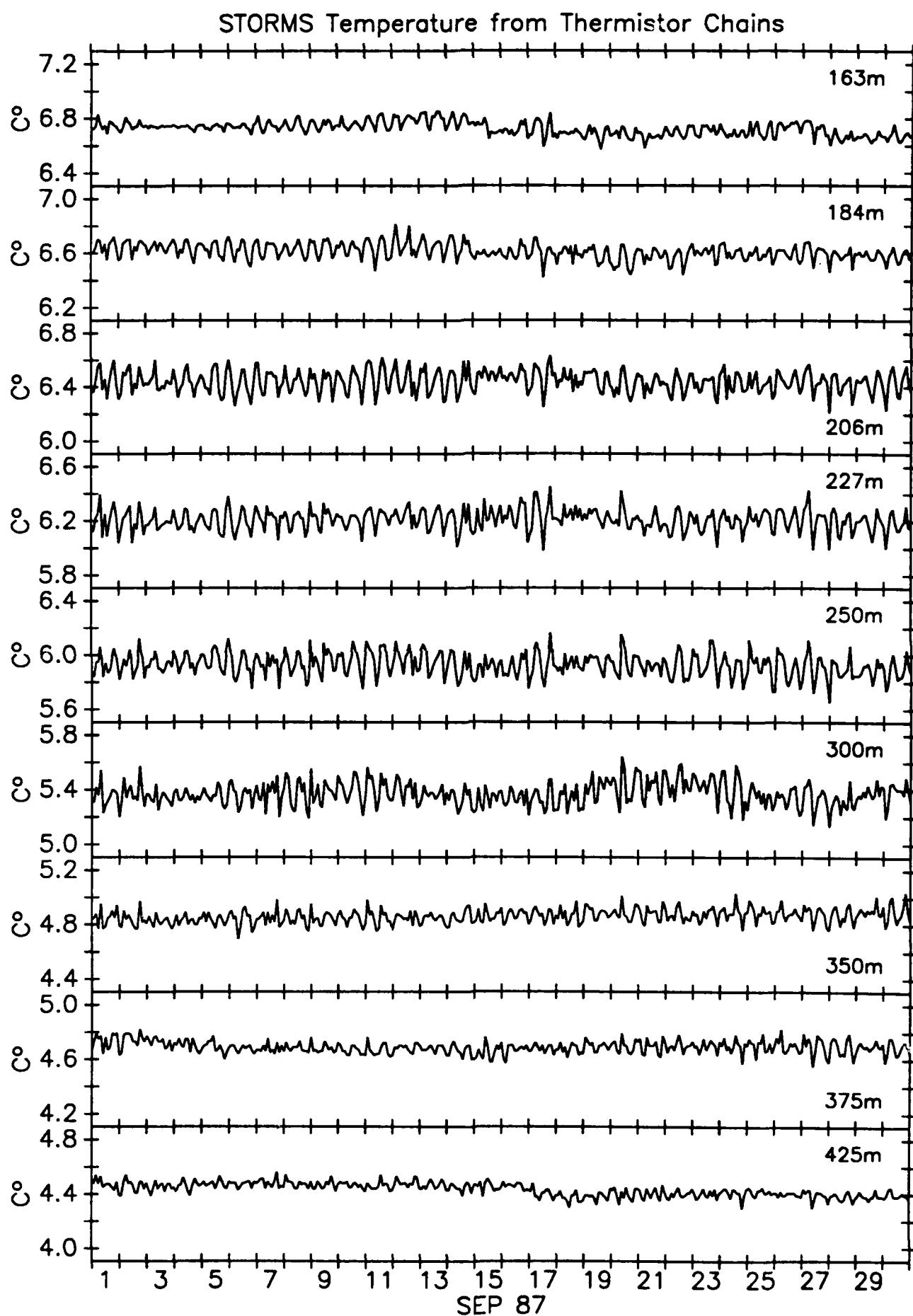
STORMS Temperatures from SEACAT & VMCM

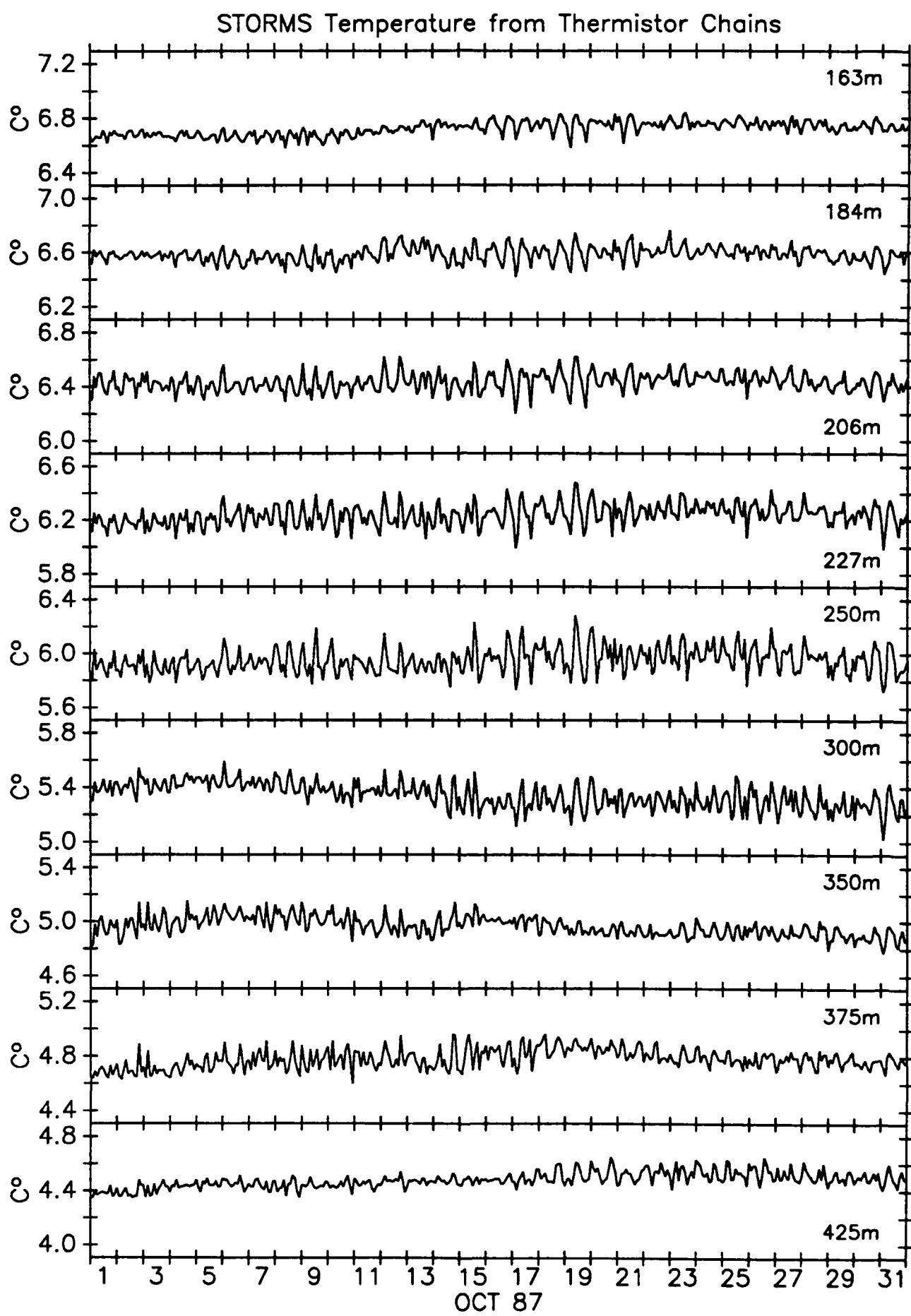


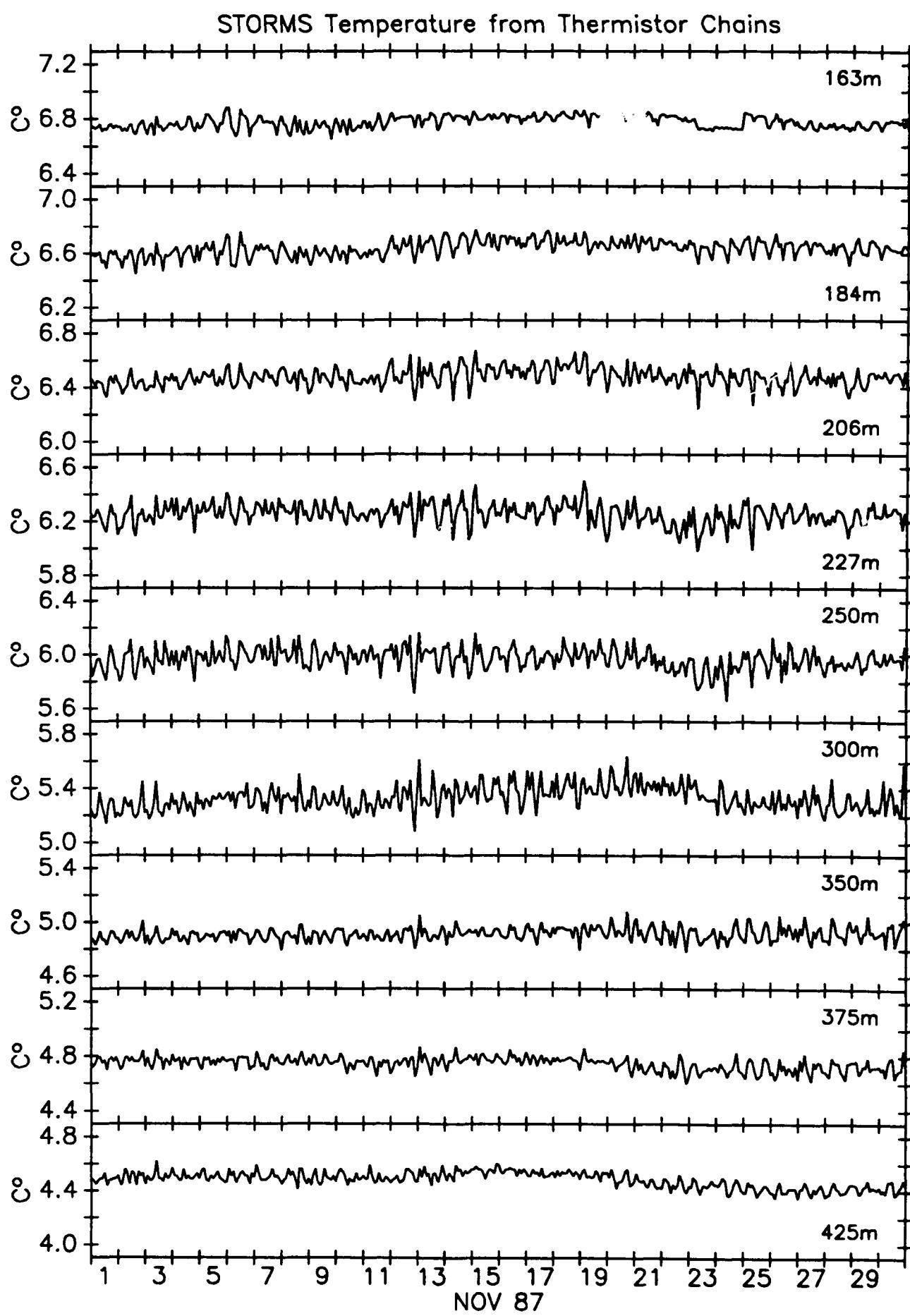
TIME SERIES OF TEMPERATURE: UNFILTERED

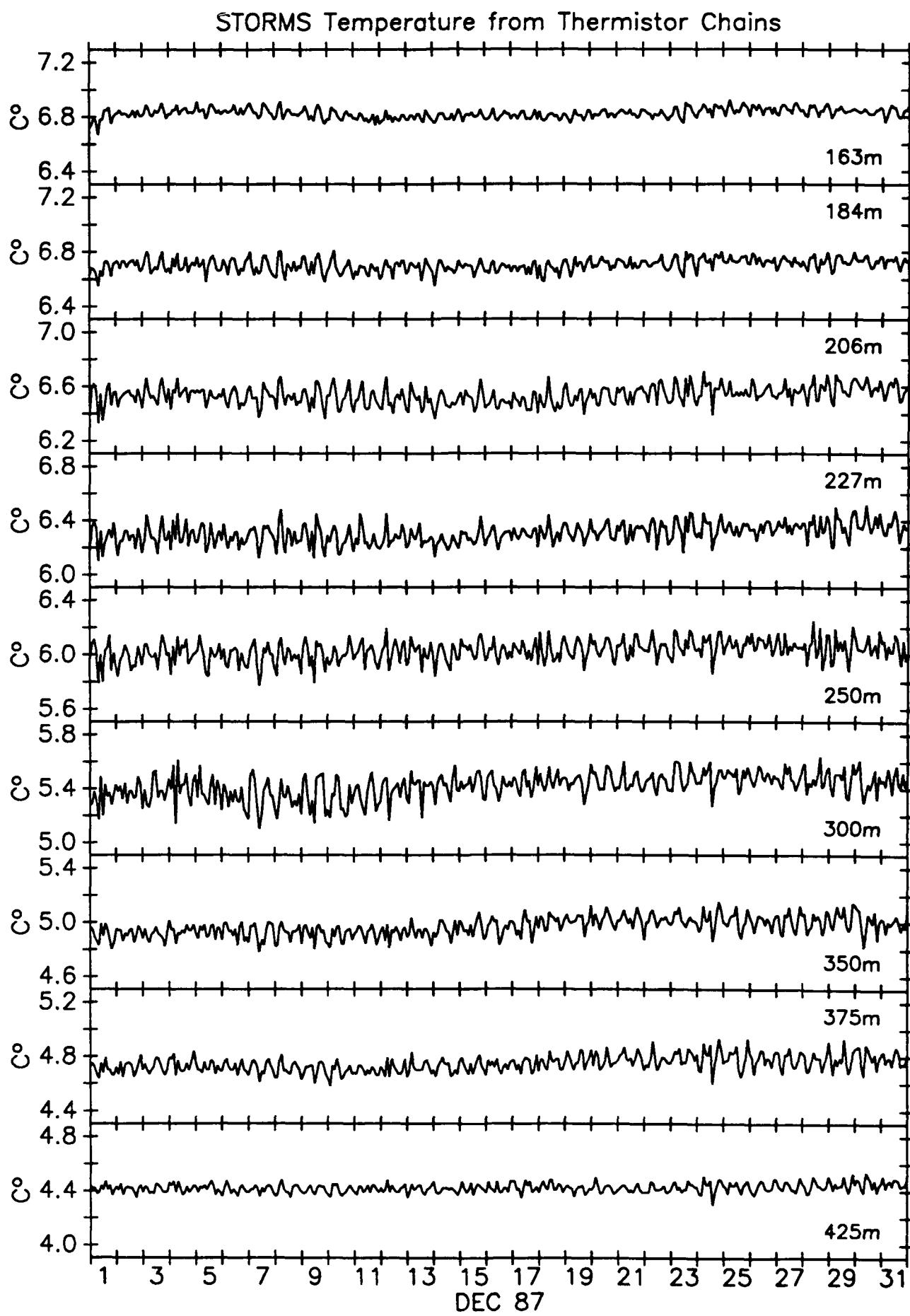
On the following 11 pages are observations from 163 to 425 m from selected thermistors on four thermistor chains. One month is plotted per page. Sampling interval is 2 hours.

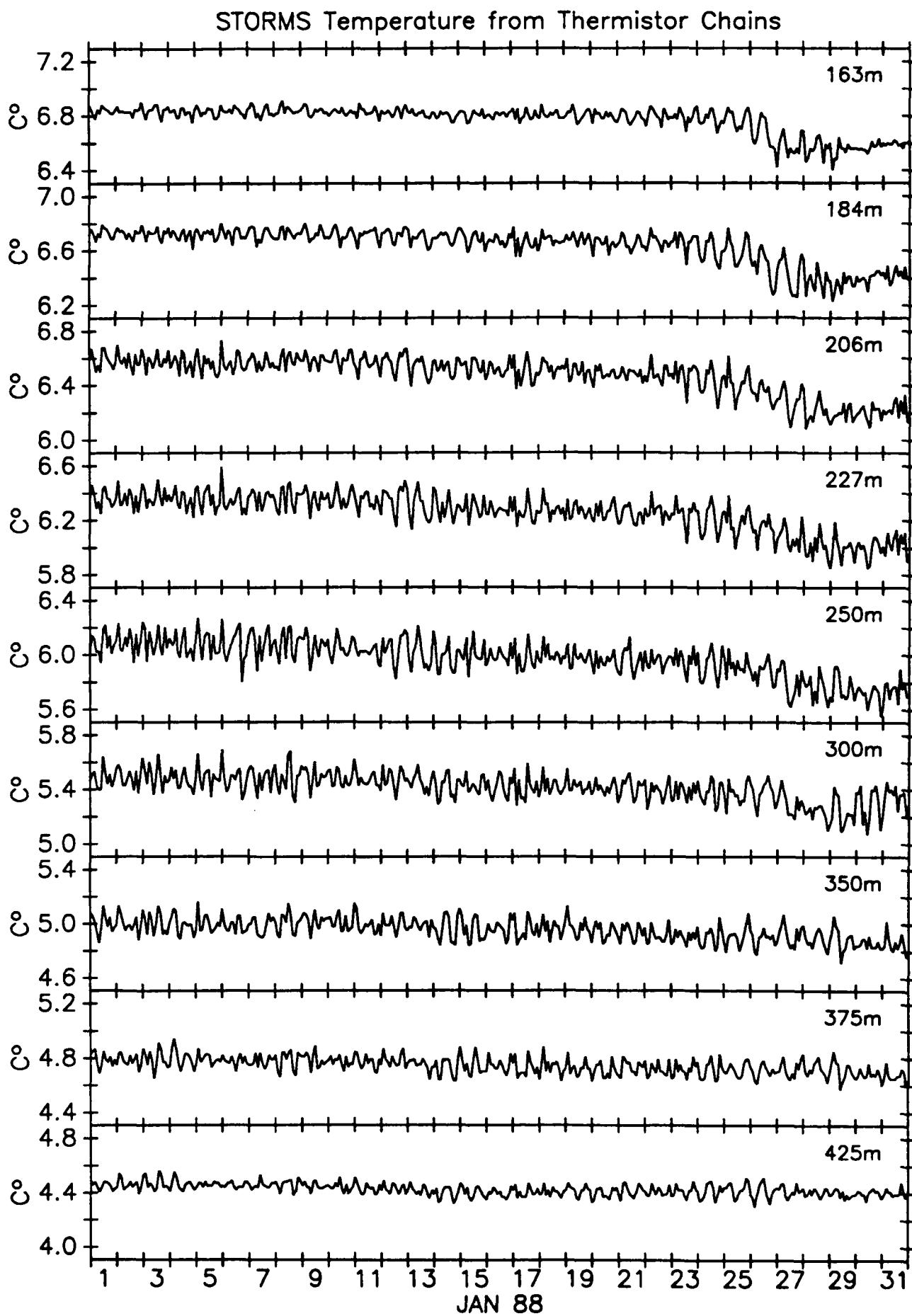


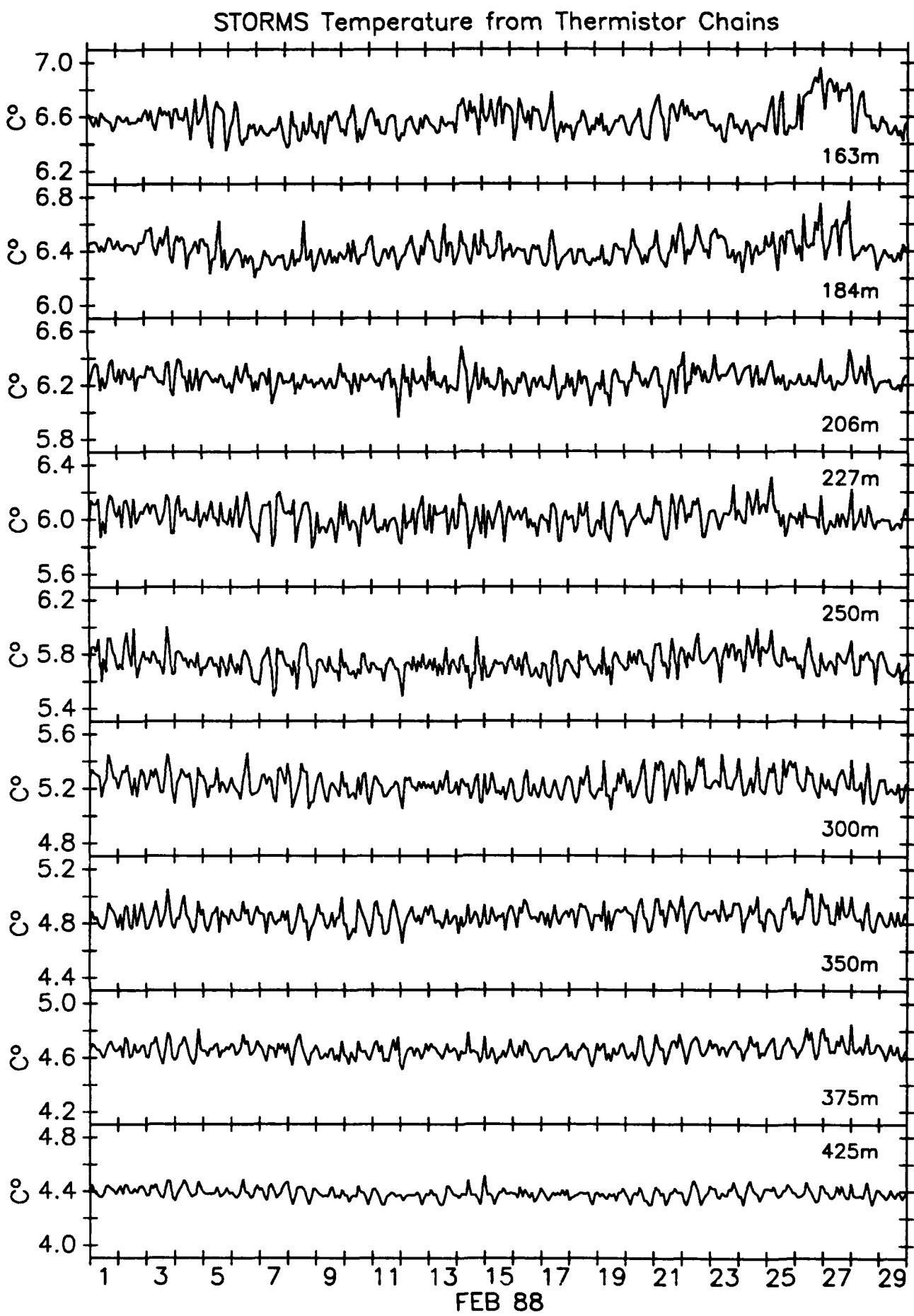




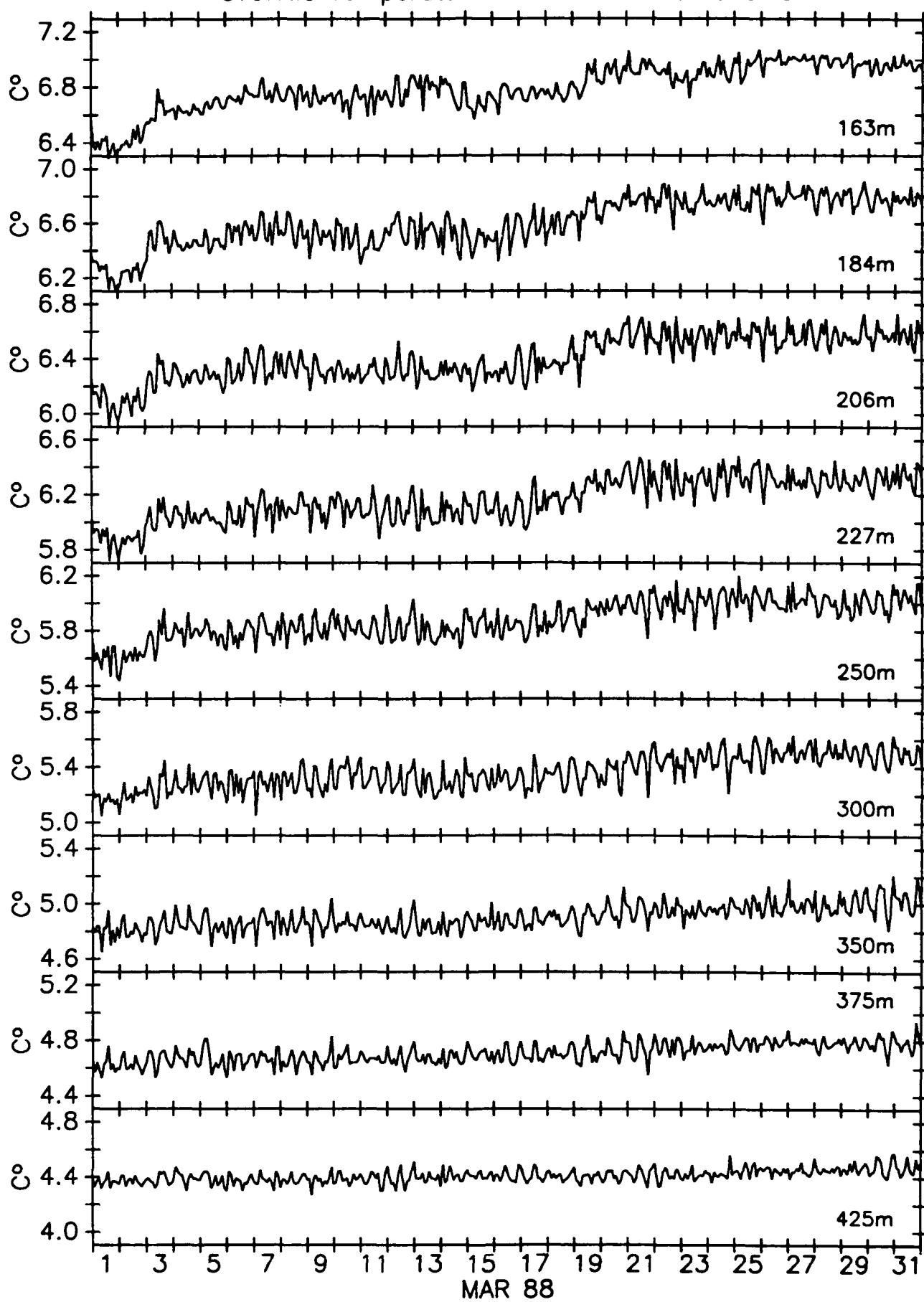


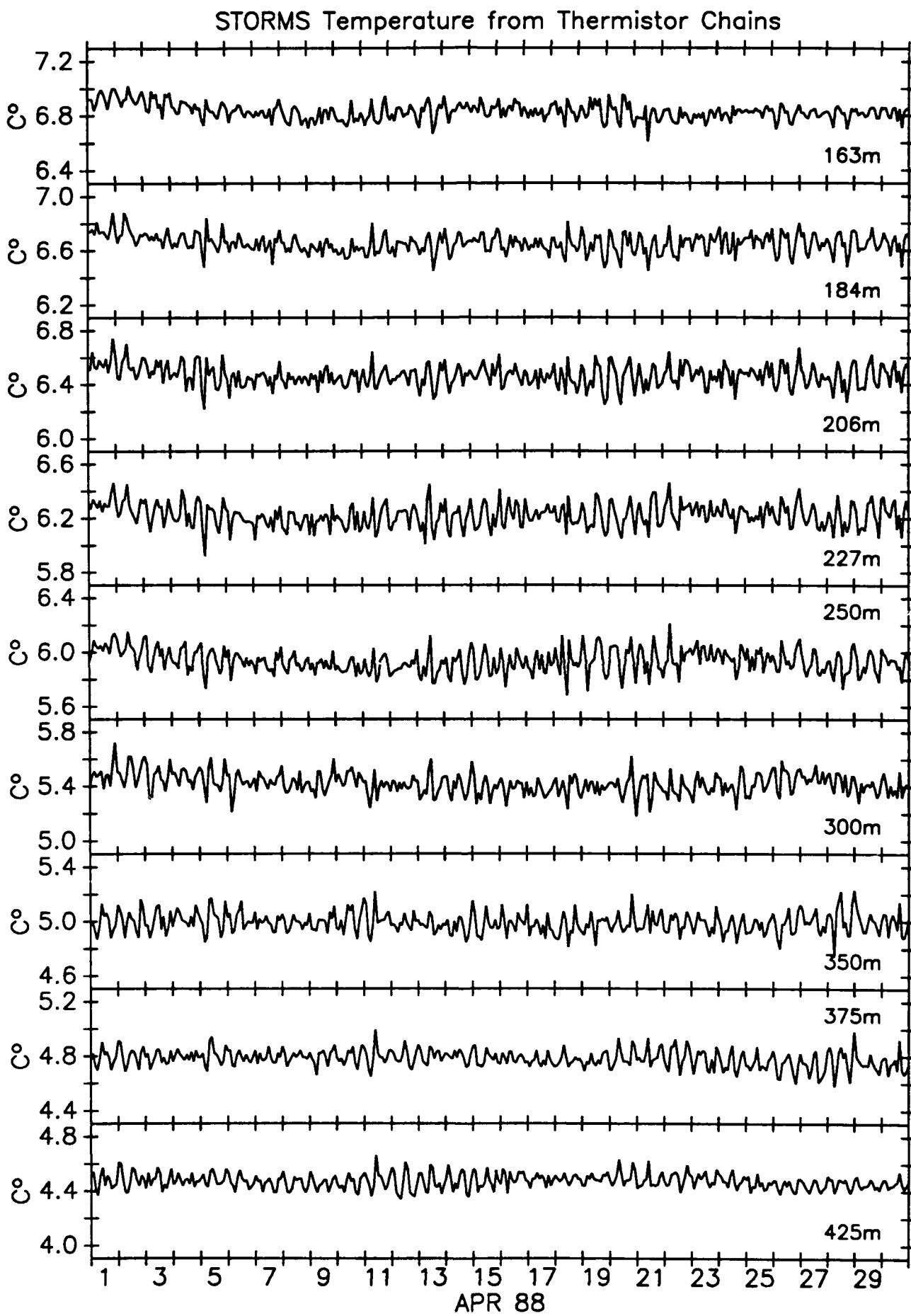


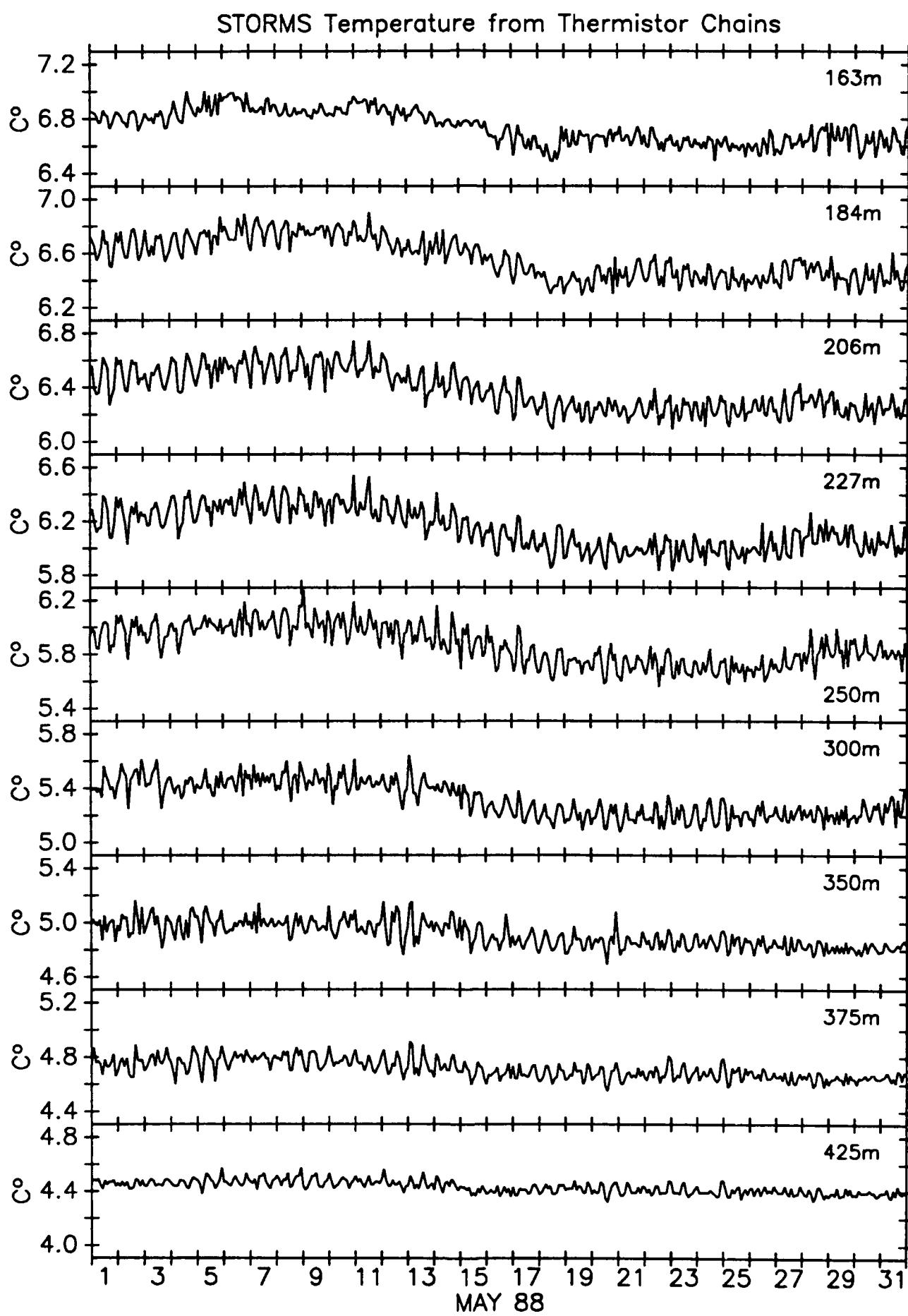


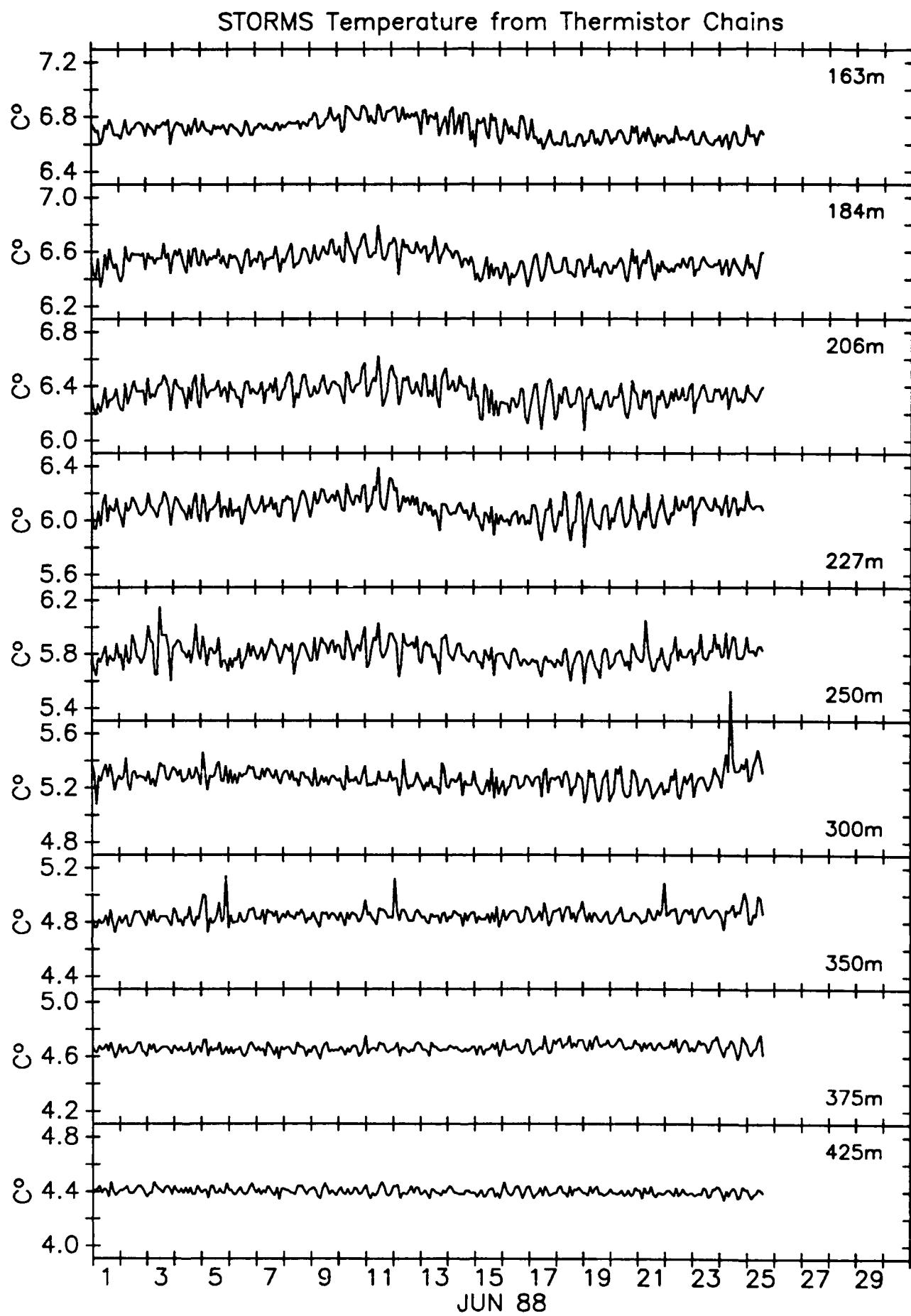


STORMS Temperature from Thermistor Chains



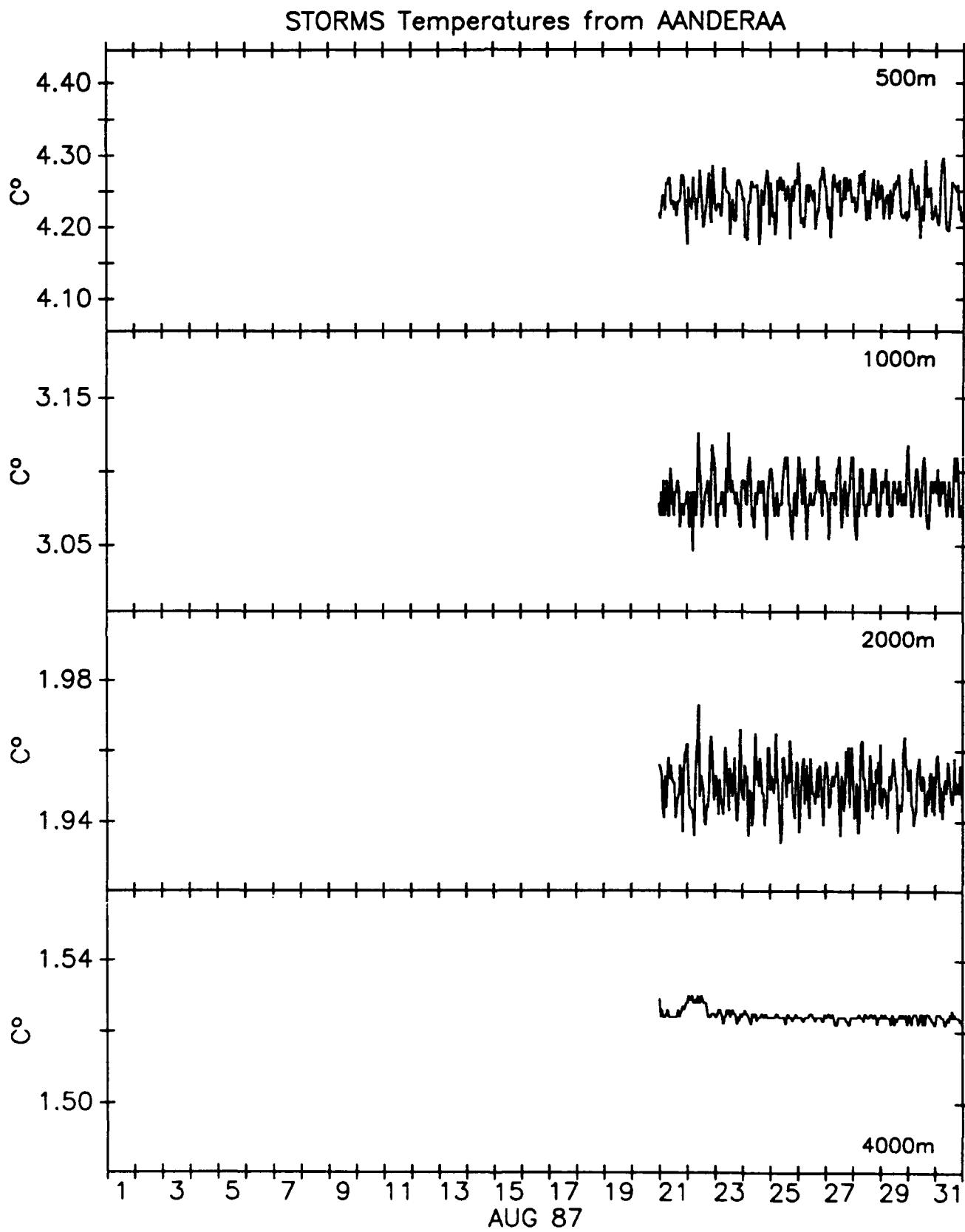


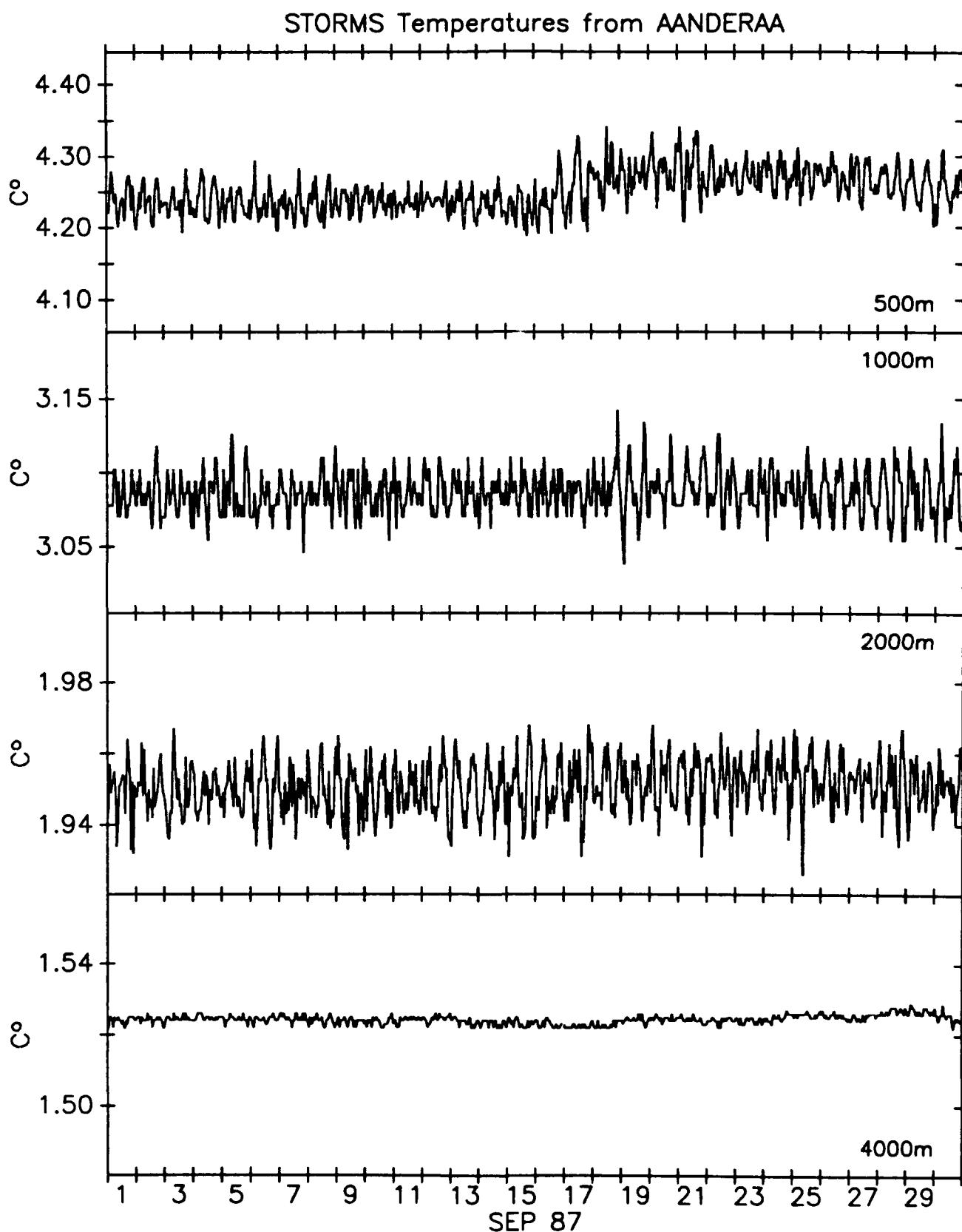


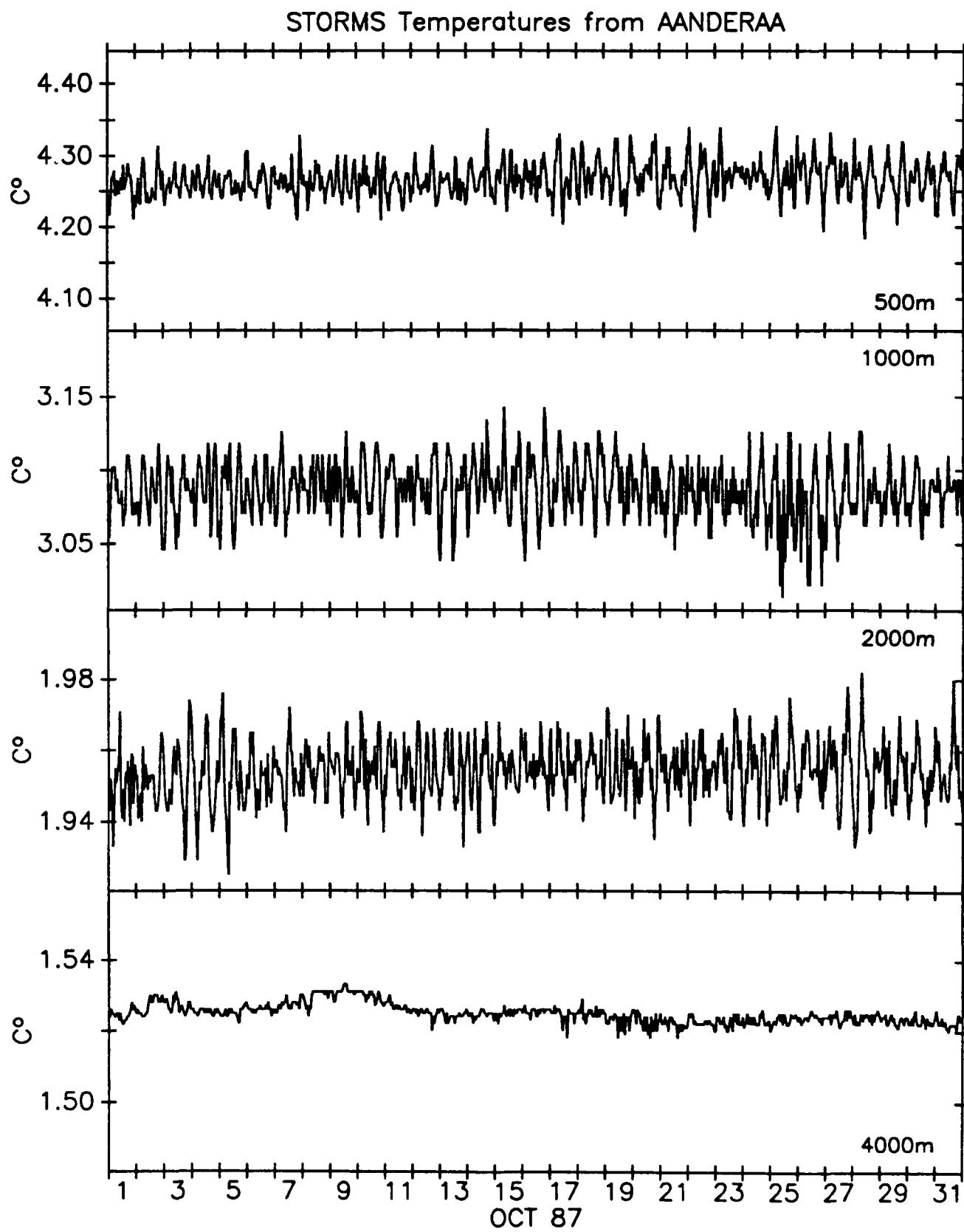


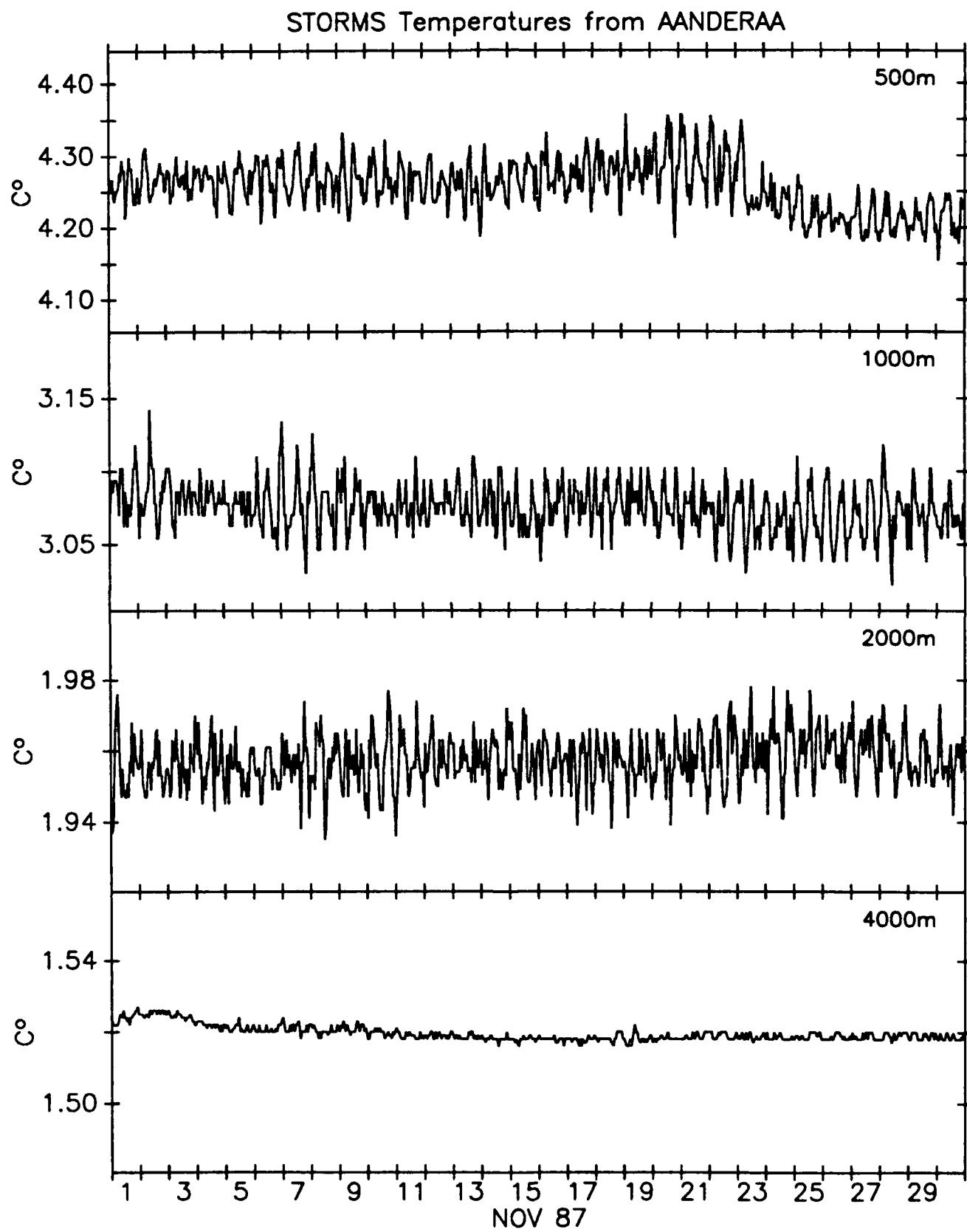
TIME SERIES OF TEMPERATURE: UNFILTERED

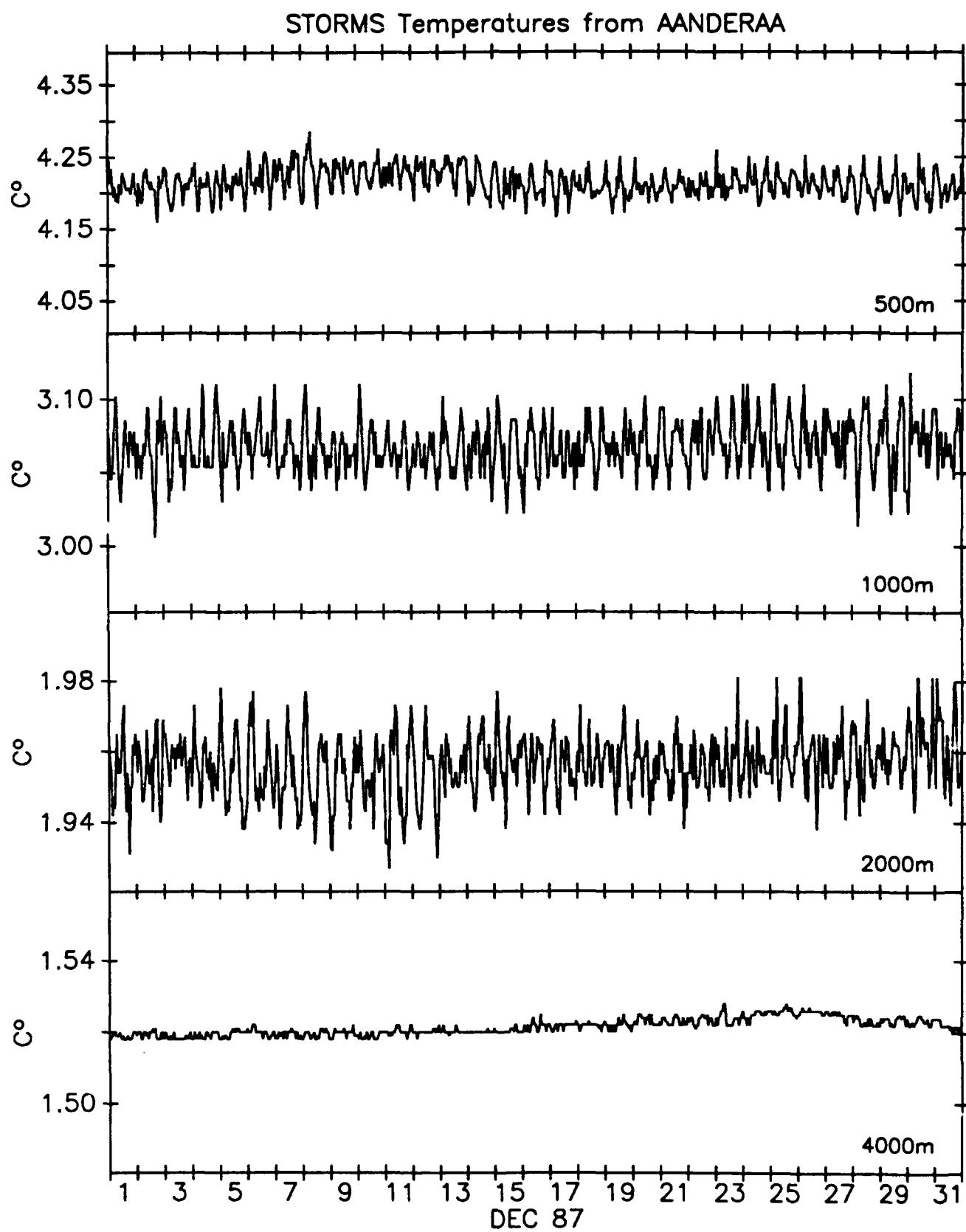
On the following 11 pages are observations from RCM-5s at 500, 1000, 2000, and 4000 m. One month is plotted per page; sampling interval is 1 hour.

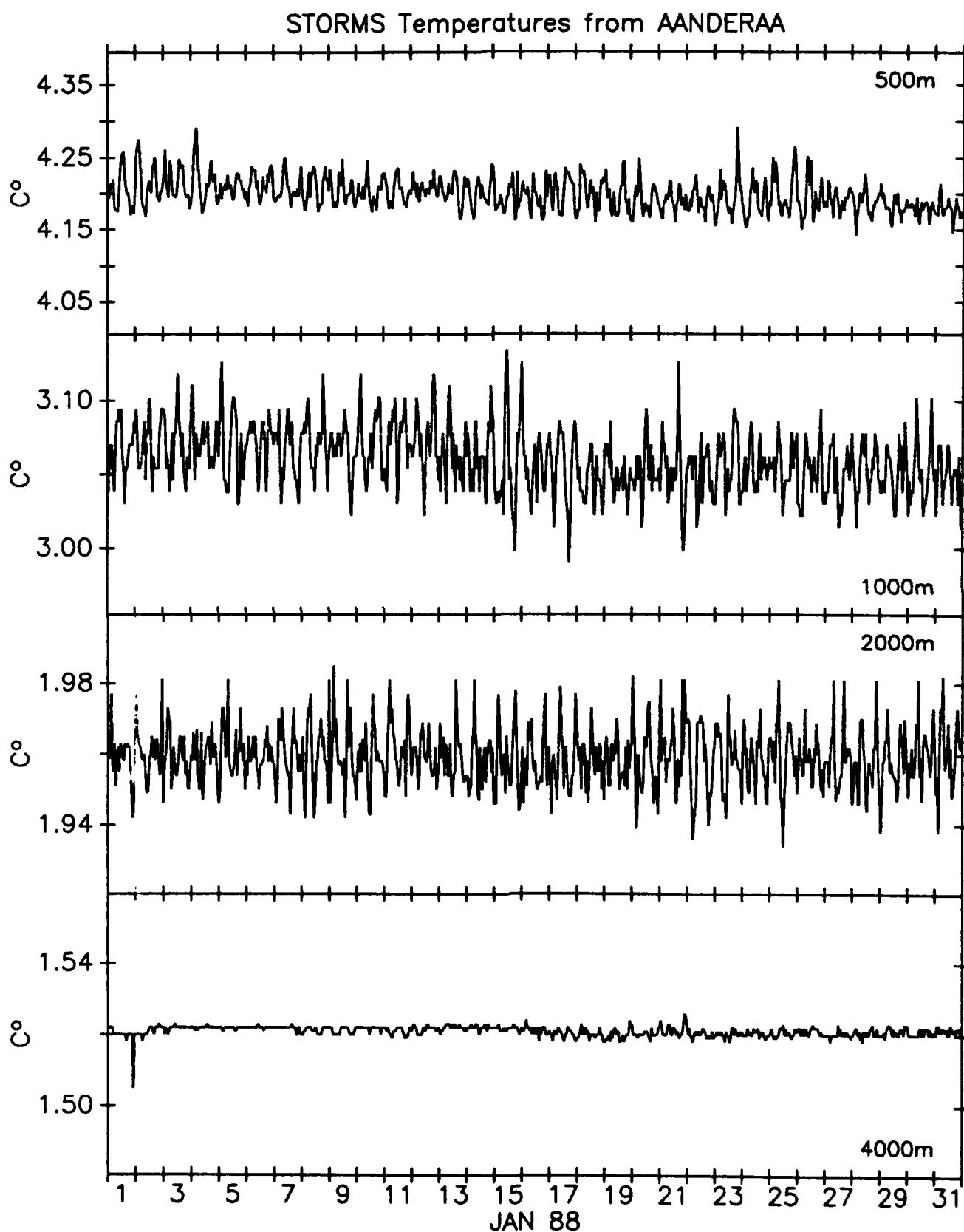


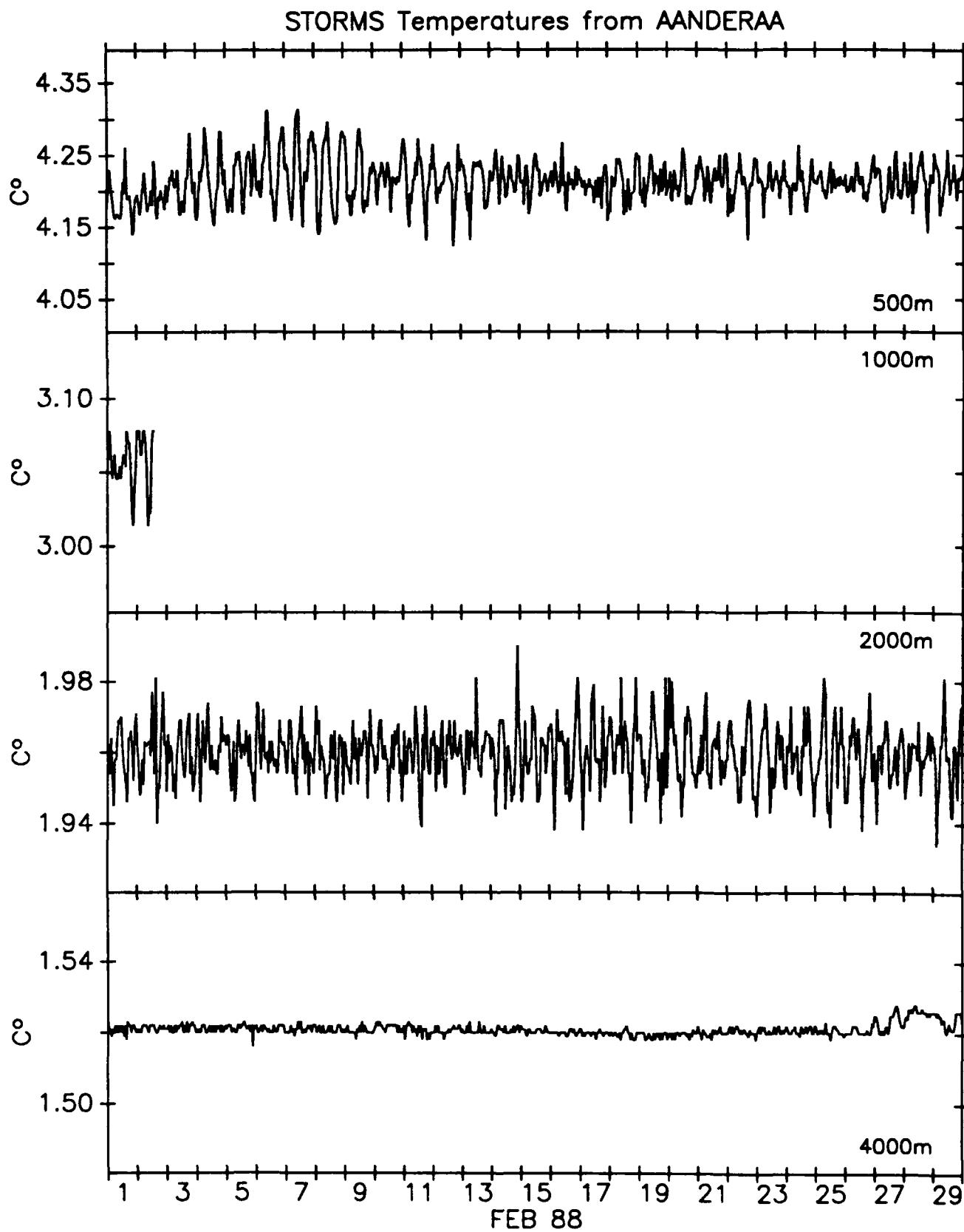


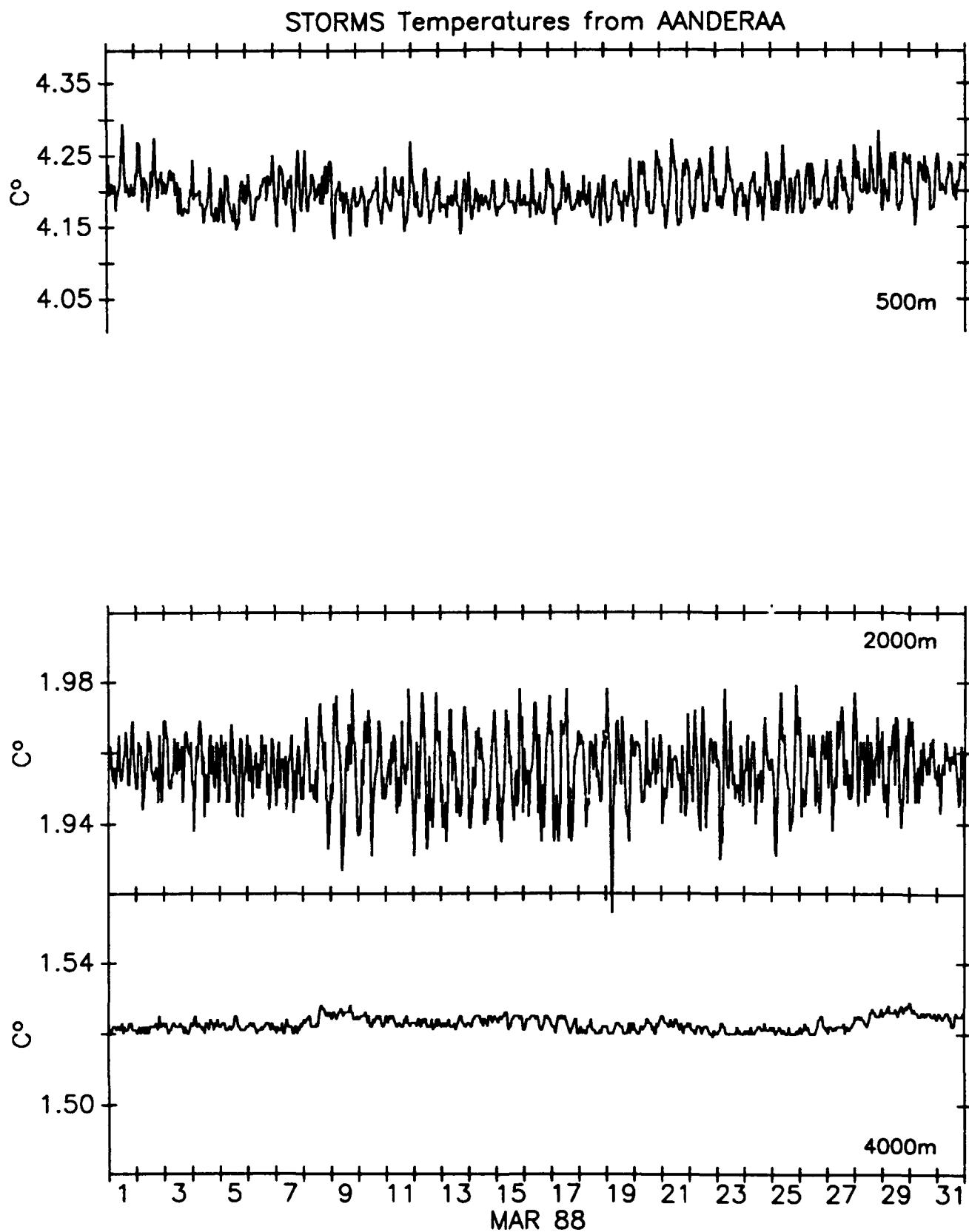


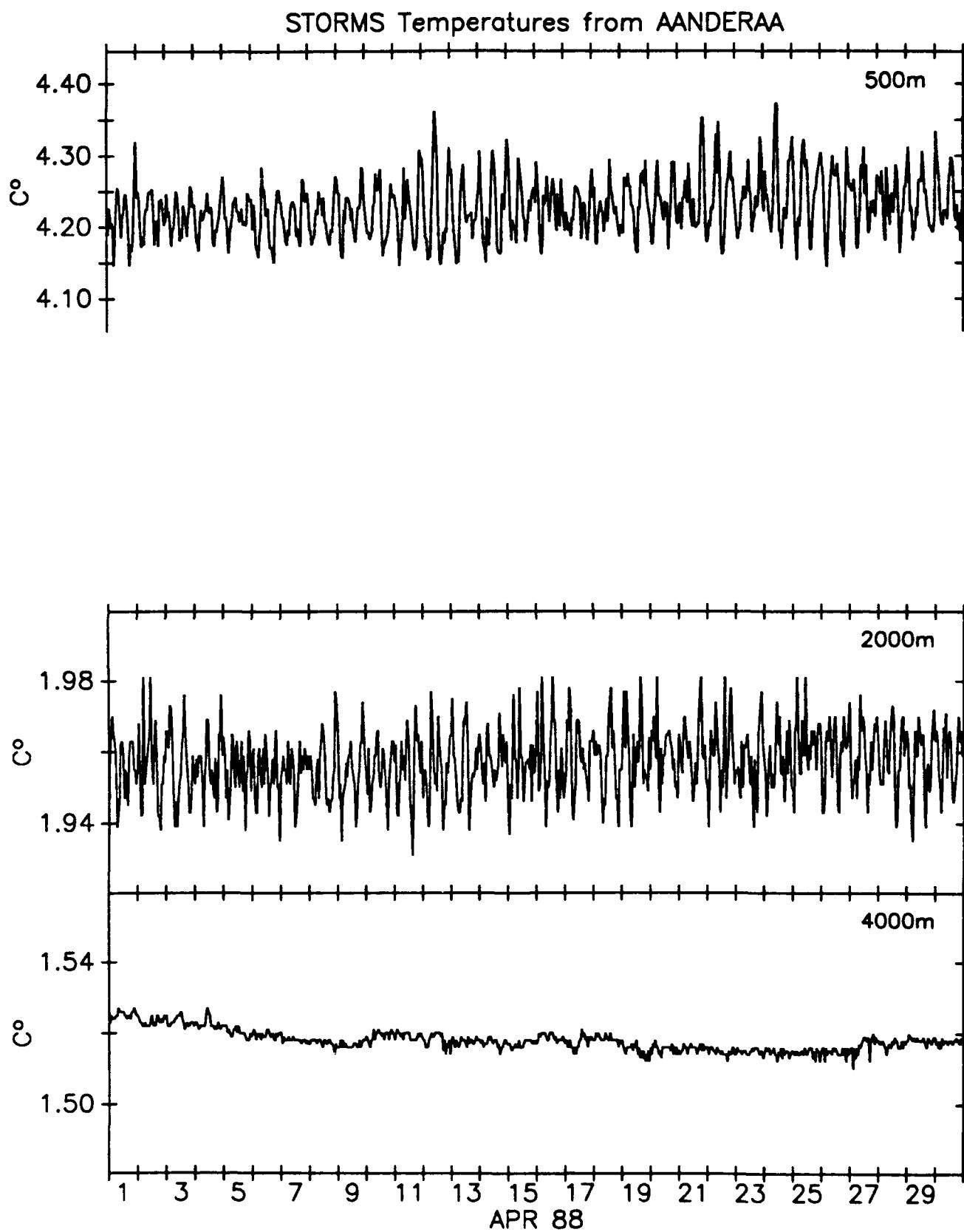




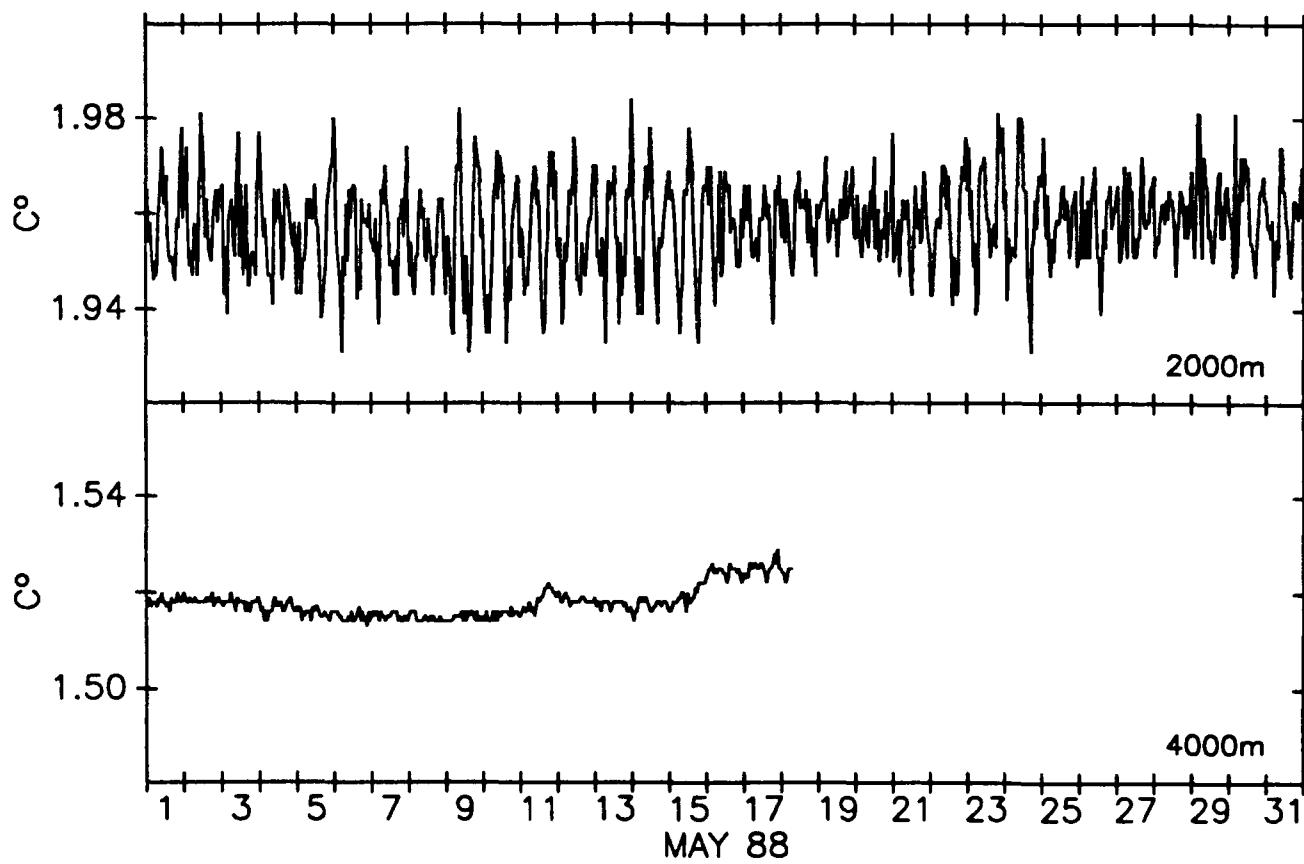
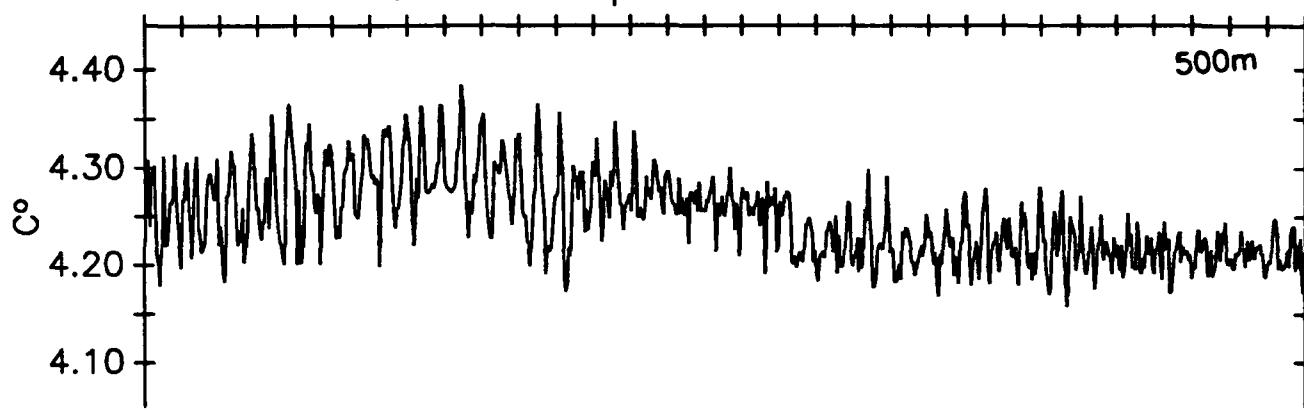


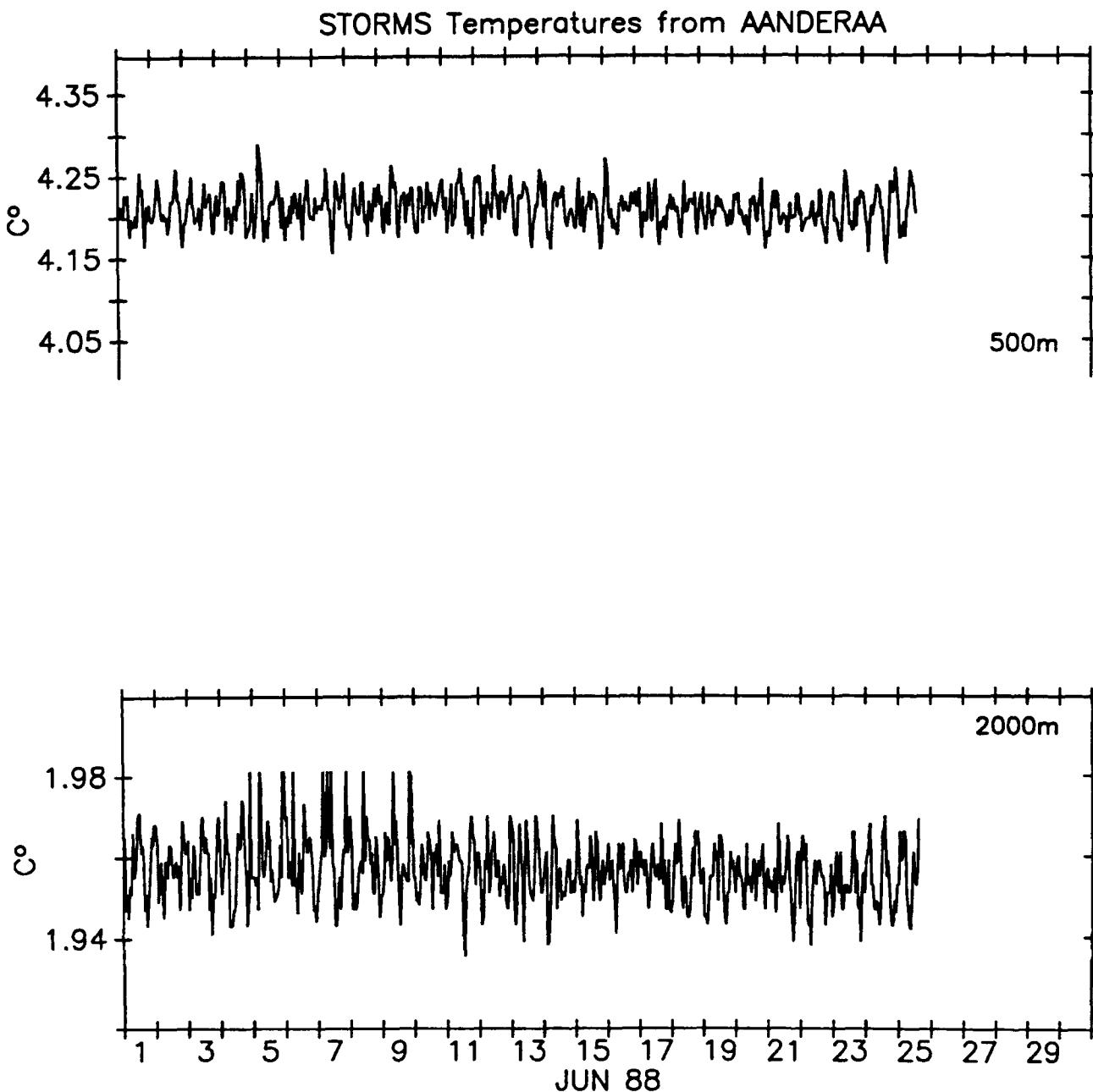






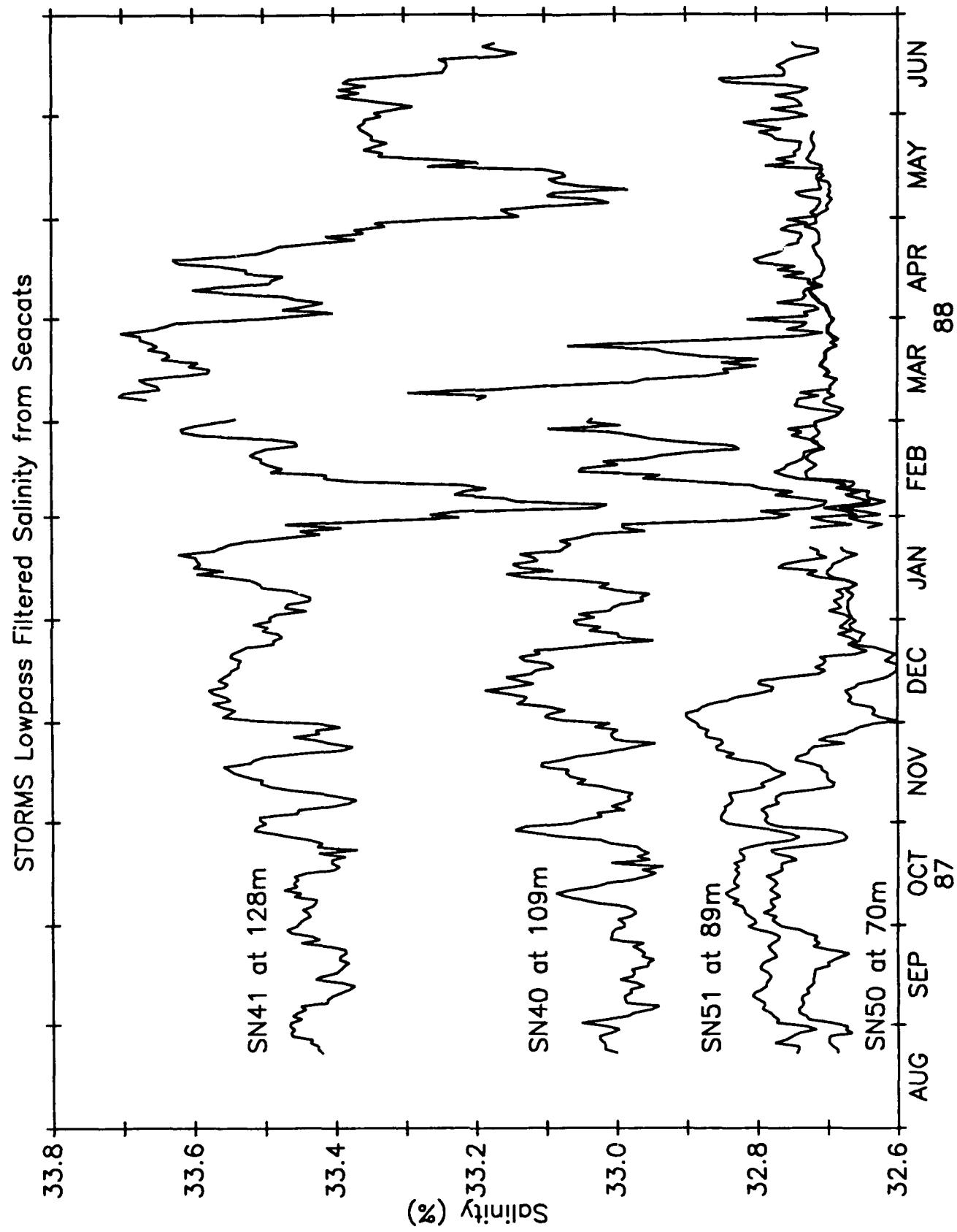
STORMS Temperatures from AANDERAA





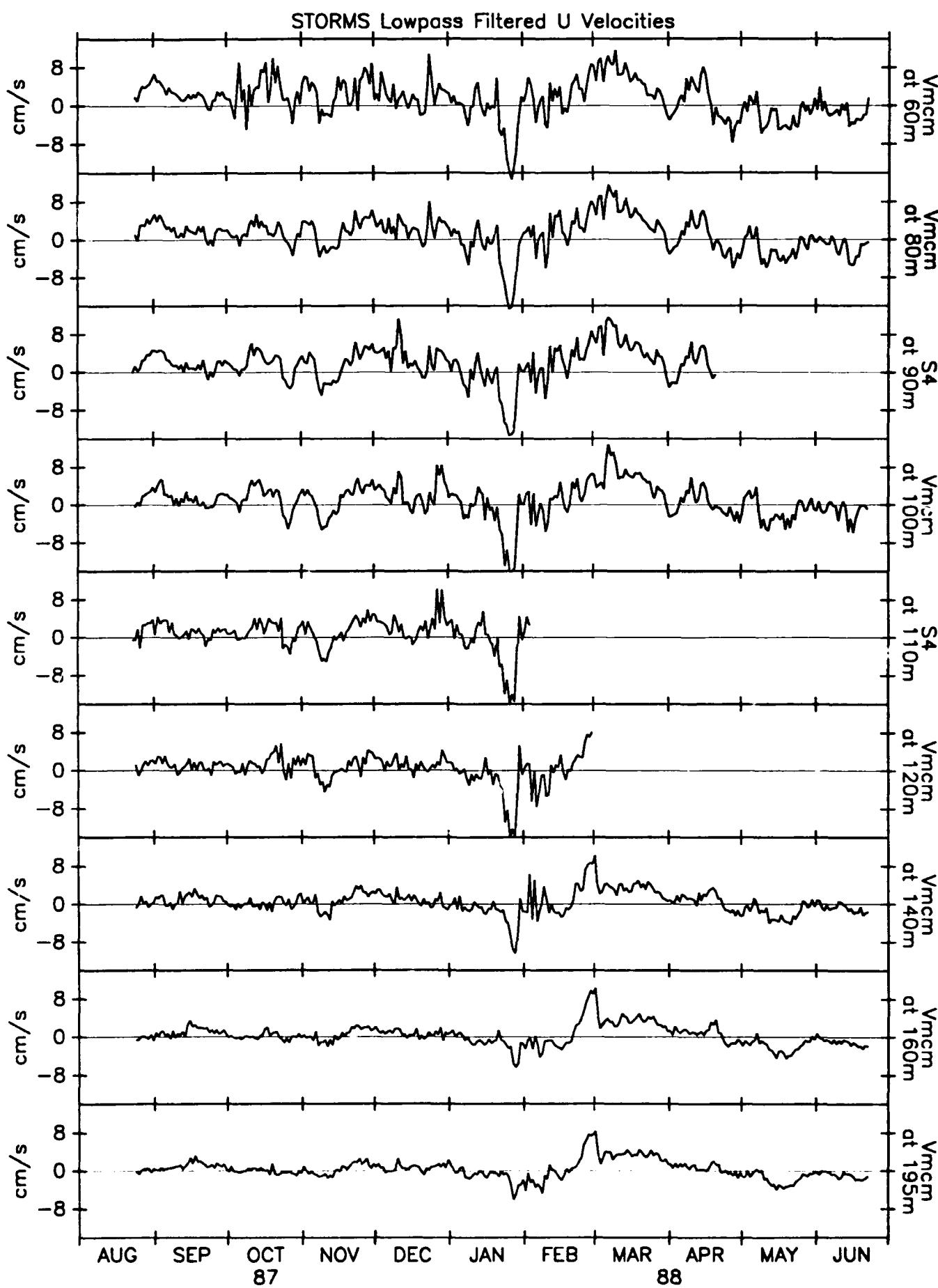
TIME SERIES OF SALINITY: LOW-PASS FILTERED

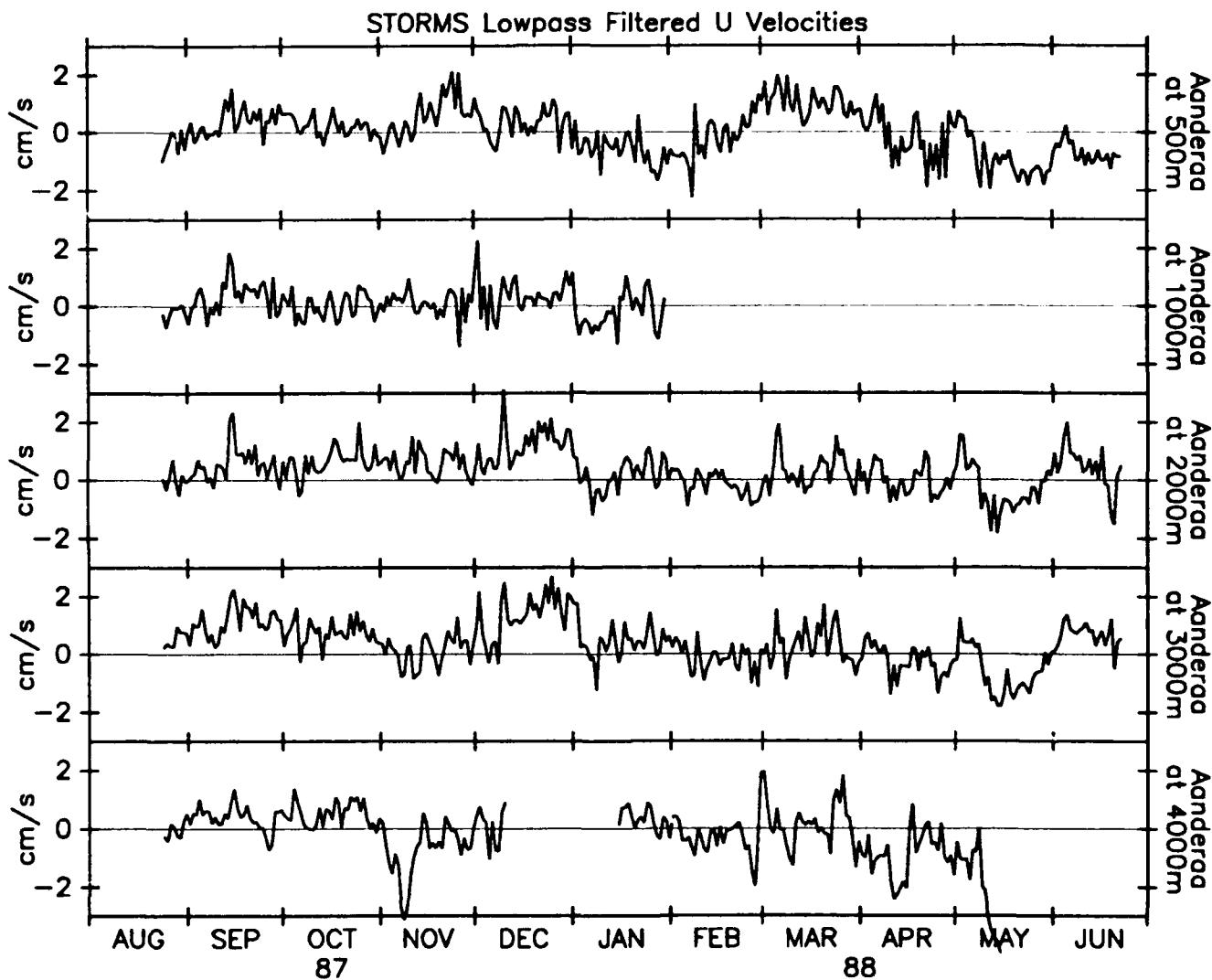
Observations of salinity calculated from temperature and conductivity measured by Seacats at 70, 89, 109 and 128 m. Data are low-pass filtered (40 hour half-power) and decimated to daily values.



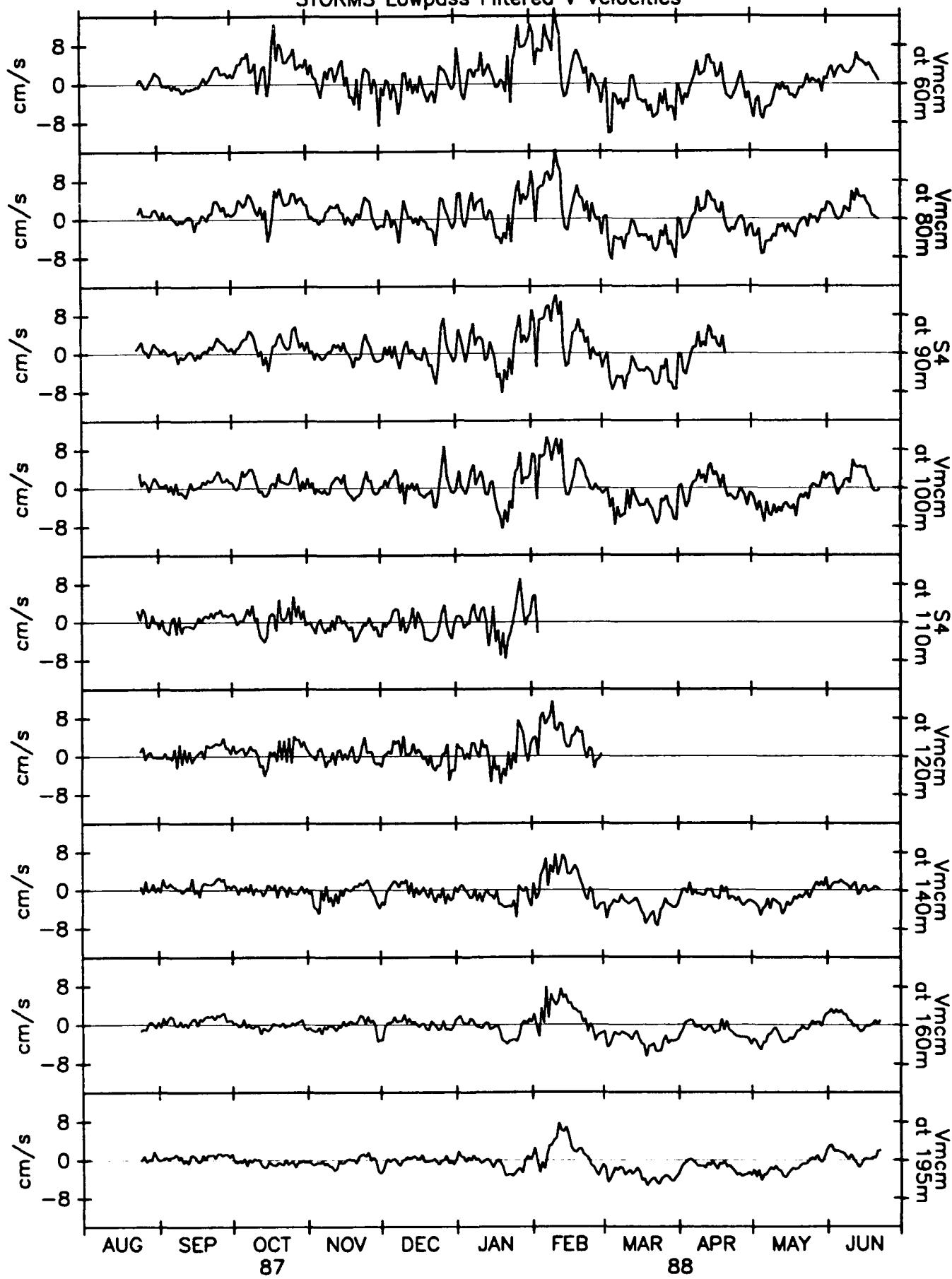
TIME SERIES OF VELOCITY: LOW-PASS FILTERED

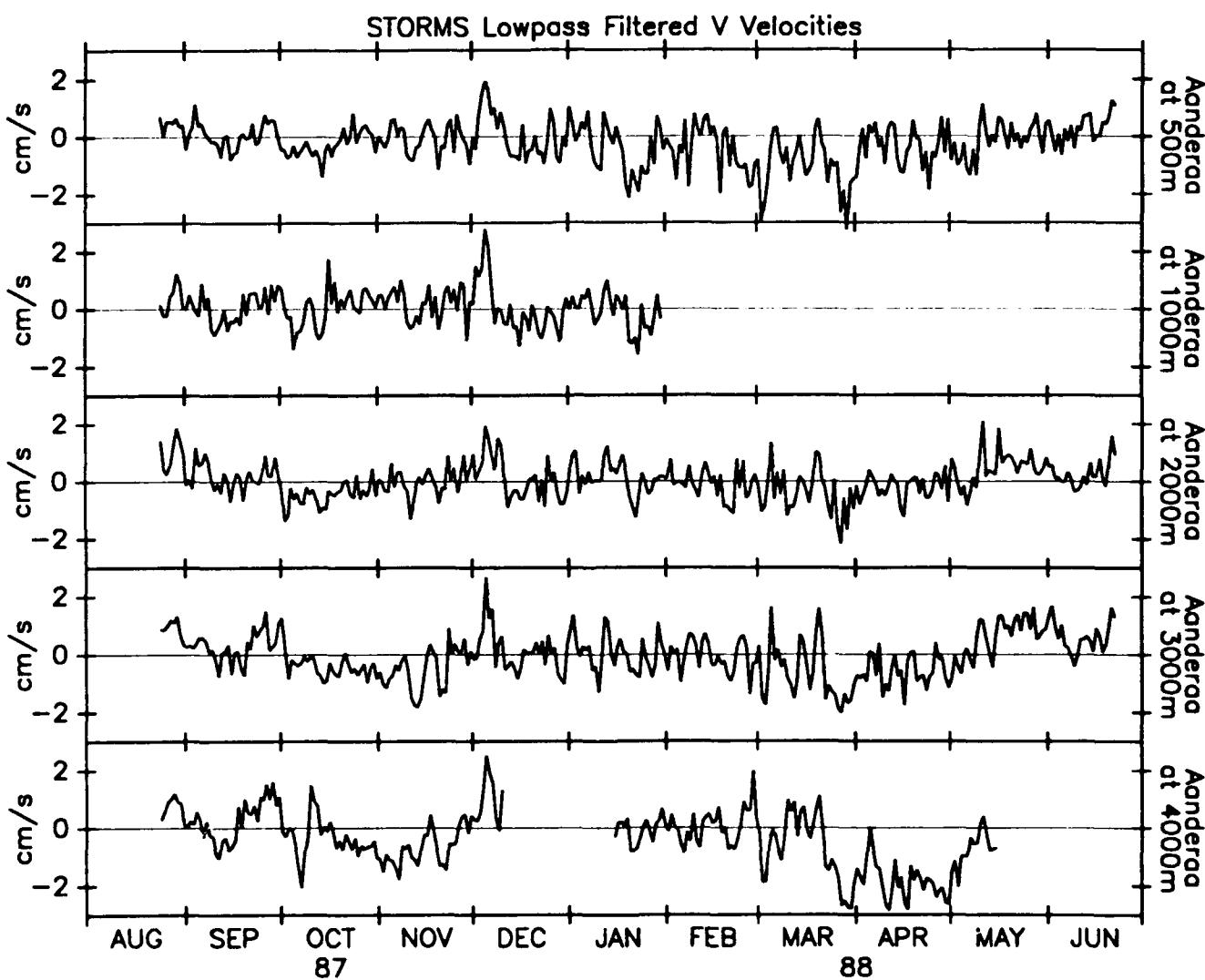
On the following 6 pages are observations from VMCMs at 60, 80, 100, 120, 140, 160 and 195 m; S-4s at 90 and 110 m; and RCM-5s at 500, 1000, 2000, 3000 and 4000 m. Velocity is displayed as u-component, v-component and vector stick plot. Data are low-pass filtered (40 hour half-power) and decimated to daily values.

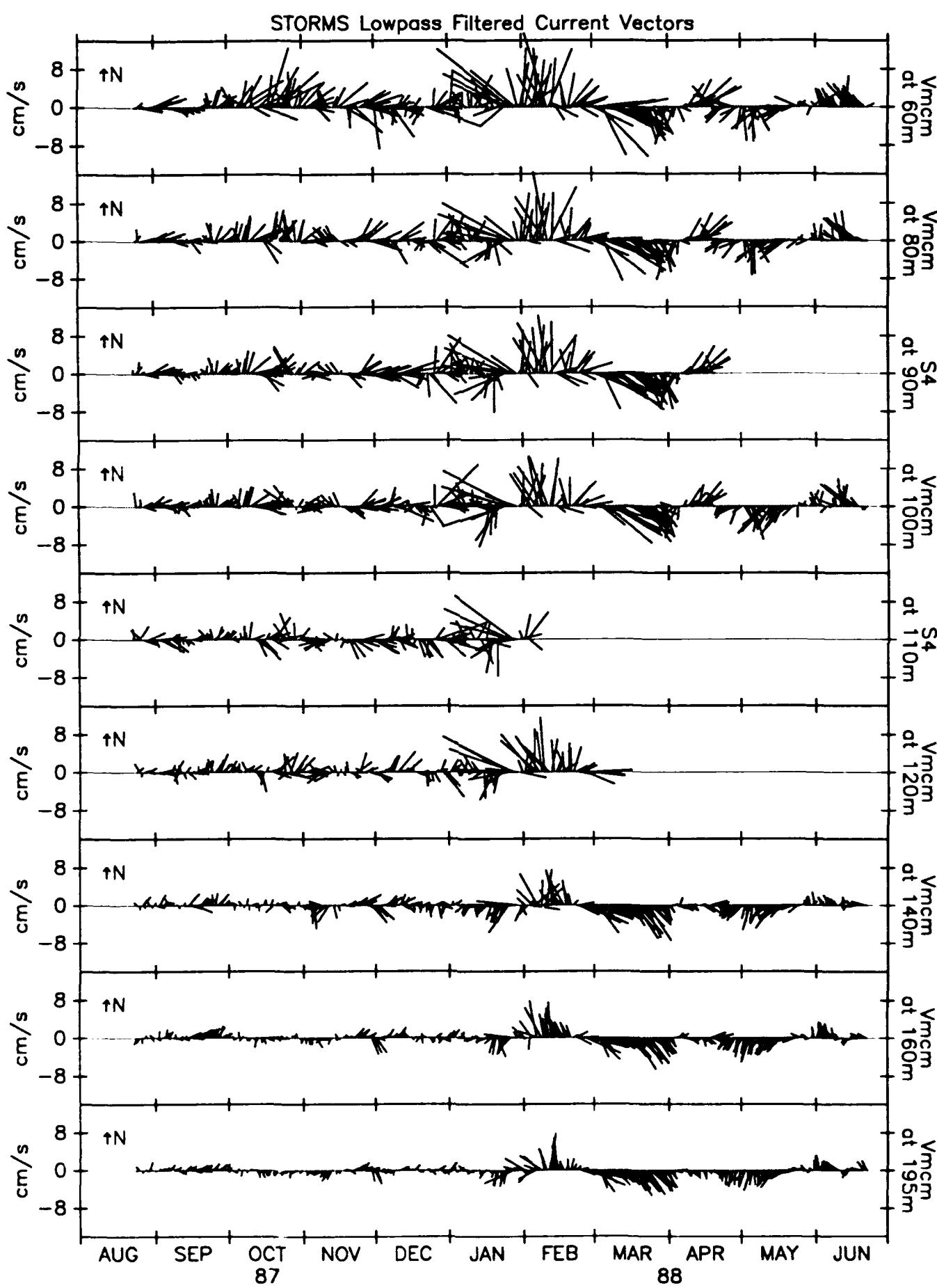


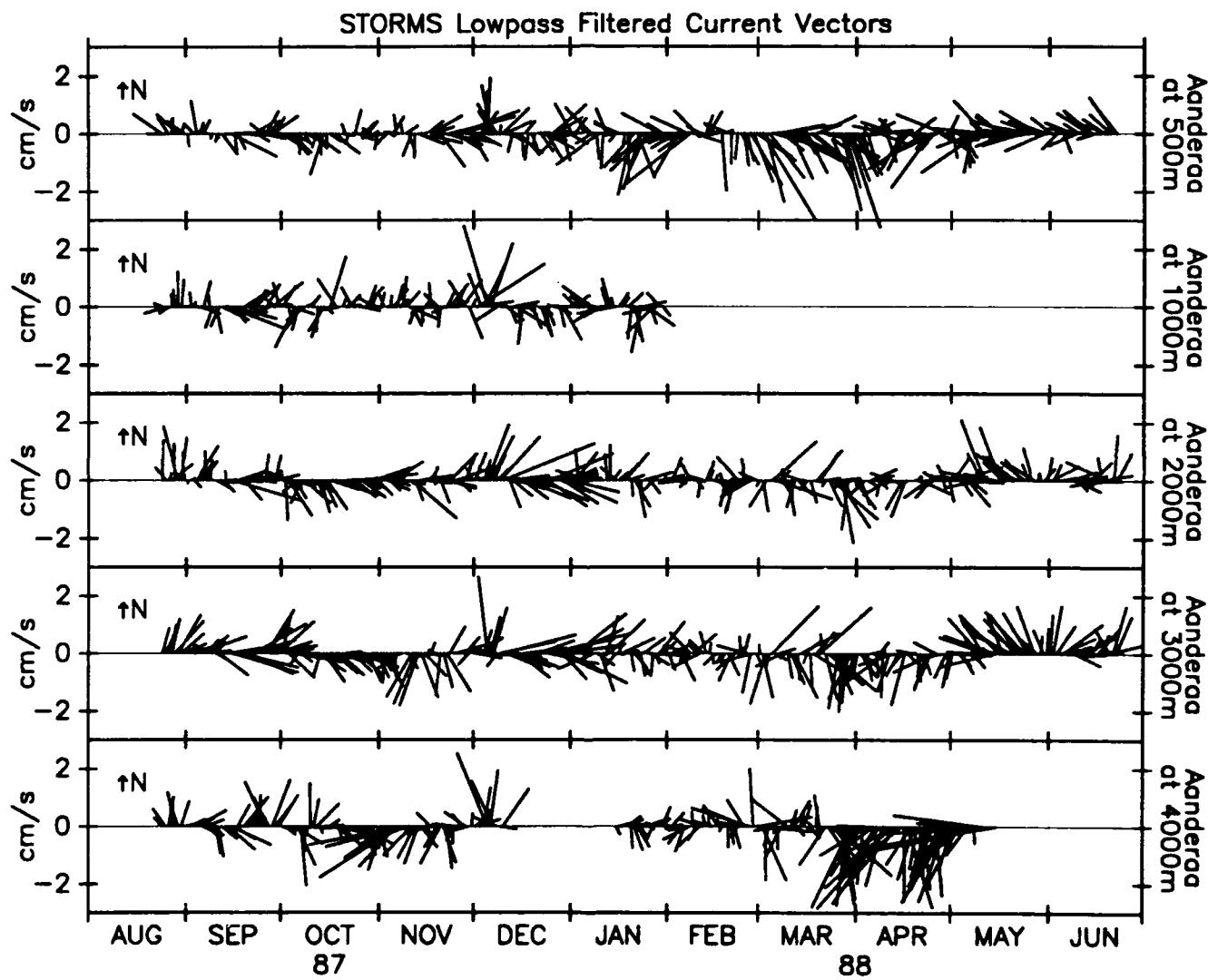


STORMS Lowpass Filtered V Velocities



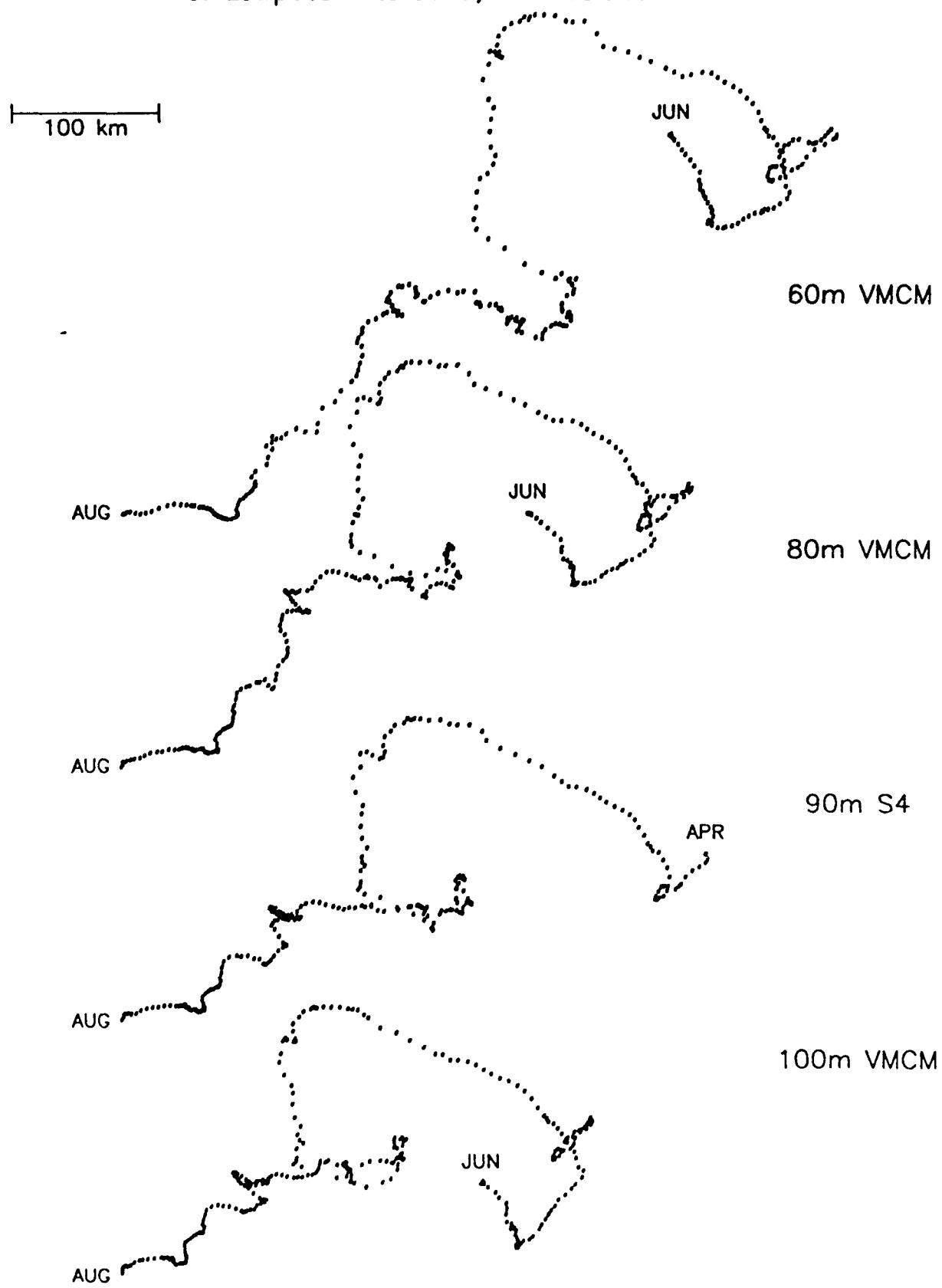


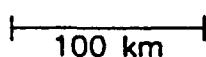




TIME SERIES OF VELOCITY: LOW-PASS FILTERED

On the following 3 pages are progressive vector diagrams calculated from VM-CMs at 60, 80, 100, 120, 140, 160, and 195 m; S-4s at 90 and 110 m; and RCM-5s at 500, 1000, 2000, and 3000 m. Daily values are plotted after being low-pass filtered (40 hour half-power).

STORMS Progressive Vector Diagrams
of Lowpass Filtered U, V Velocities

STORMS Progressive Vector Diagrams
of Lowpass Filtered U, V Velocities 100 km

110m S4



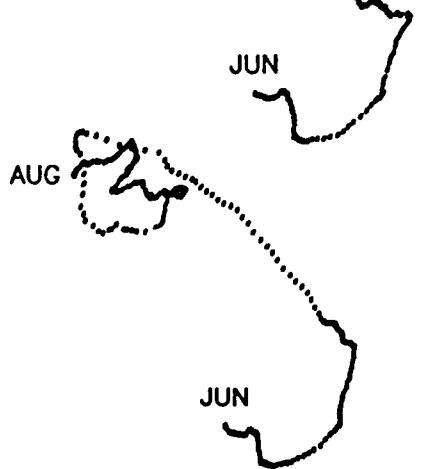
120m VMCM



140m VMCM



160m VMCM



195m VMCM

STORMS Progressive Vector Diagrams
of Lowpass Filtered U, V Velocities

100 km



500m AANDERAA



1000m AANDERAA



2000m AANDERAA

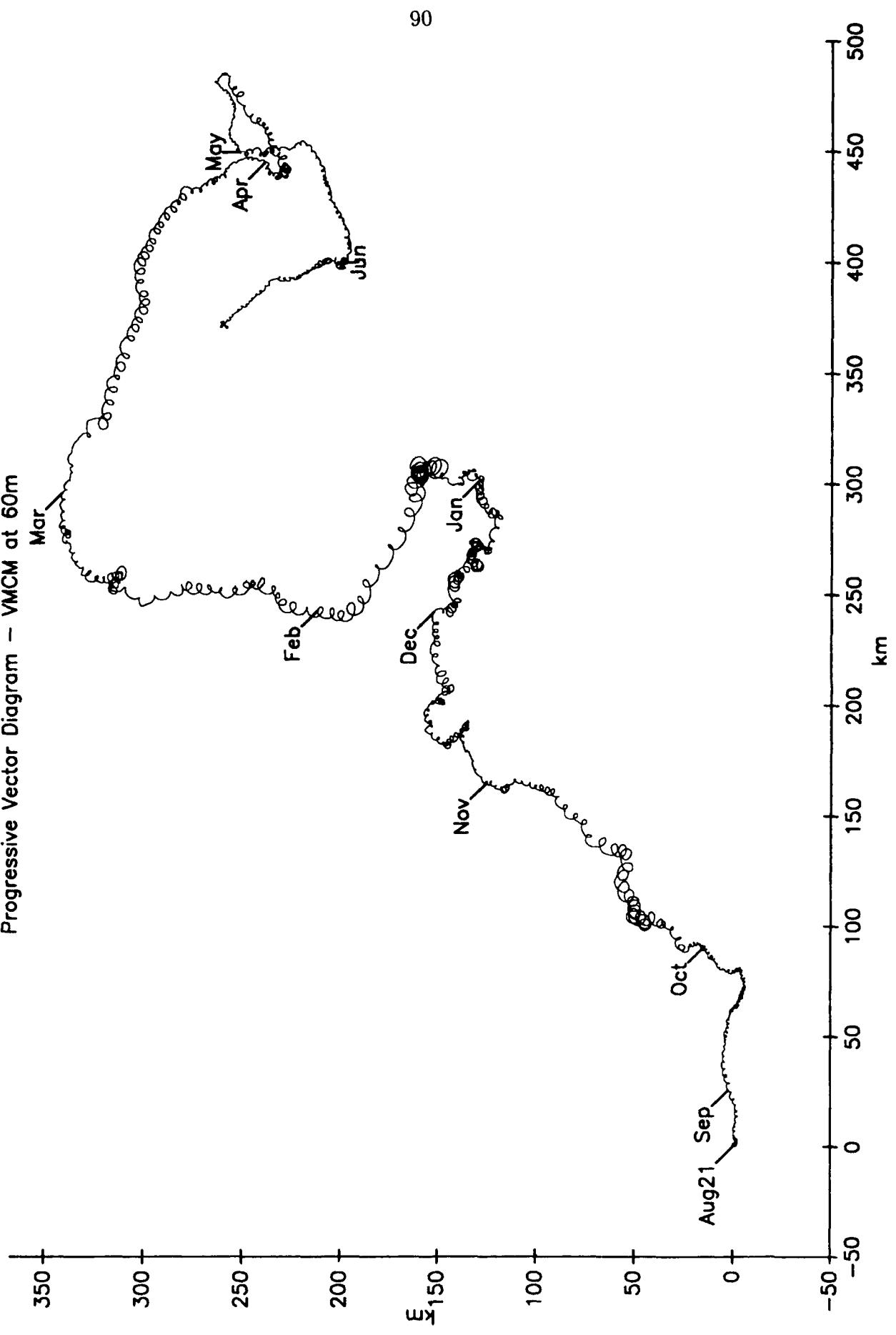


3000m AANDERAA

TIME SERIES OF VELOCITY: UNFILTERED

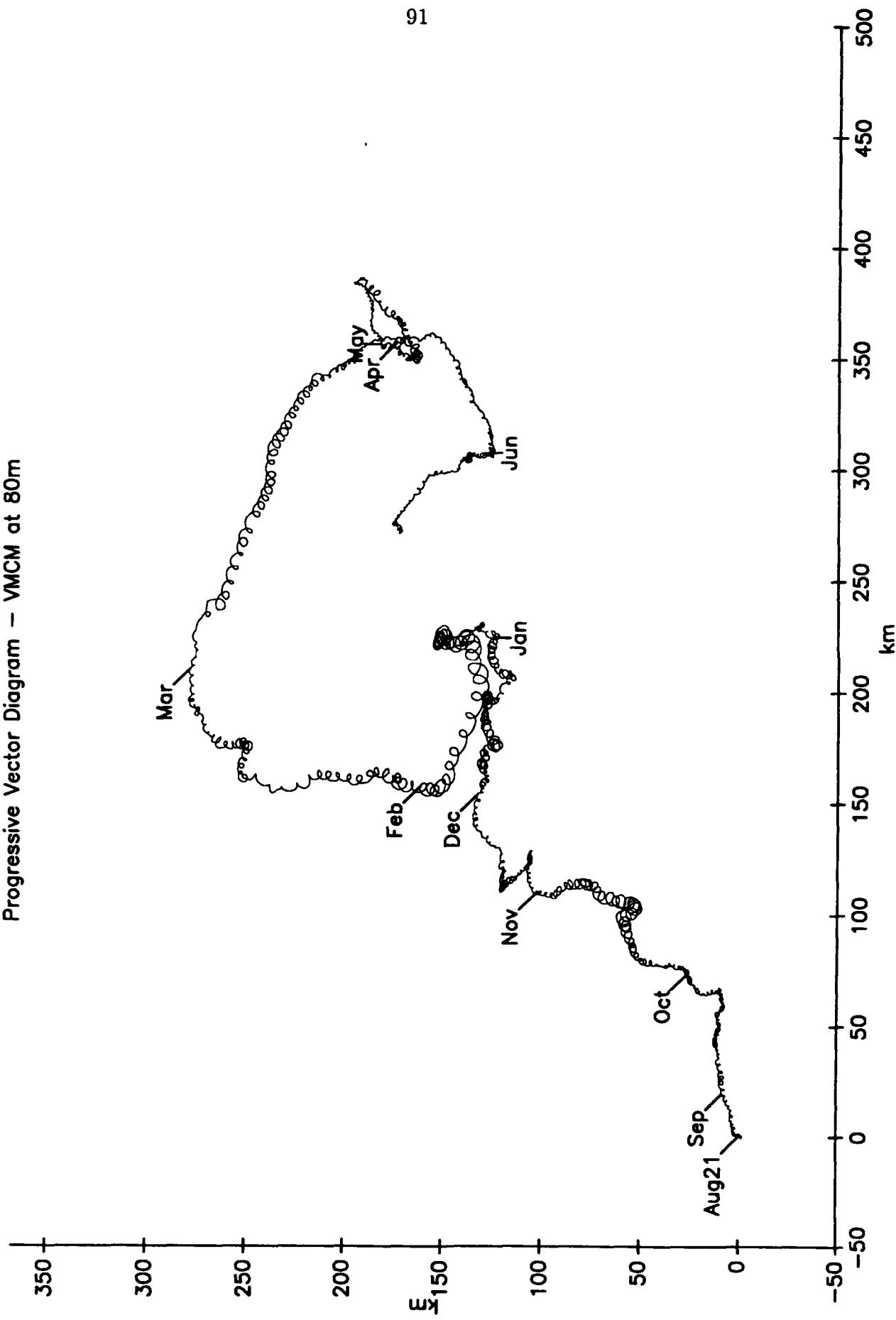
On the following 13 pages are progressive vector diagrams calculated from VM-CMs at 60, 80, 100, 120, 140, 160, and 195 m; S-4s at 90 and 110 m; and RCM-5s at 500, 1000, 2000, and 3000 m. Sampling interval is 15 minutes for VMCMs, 12 minutes for S-4s and 1 hour for RCM-5s. Note that the velocity scale changes by a factor of one-half for observations deeper than 500 m.

Progressive Vector Diagram – VMCM at 60m

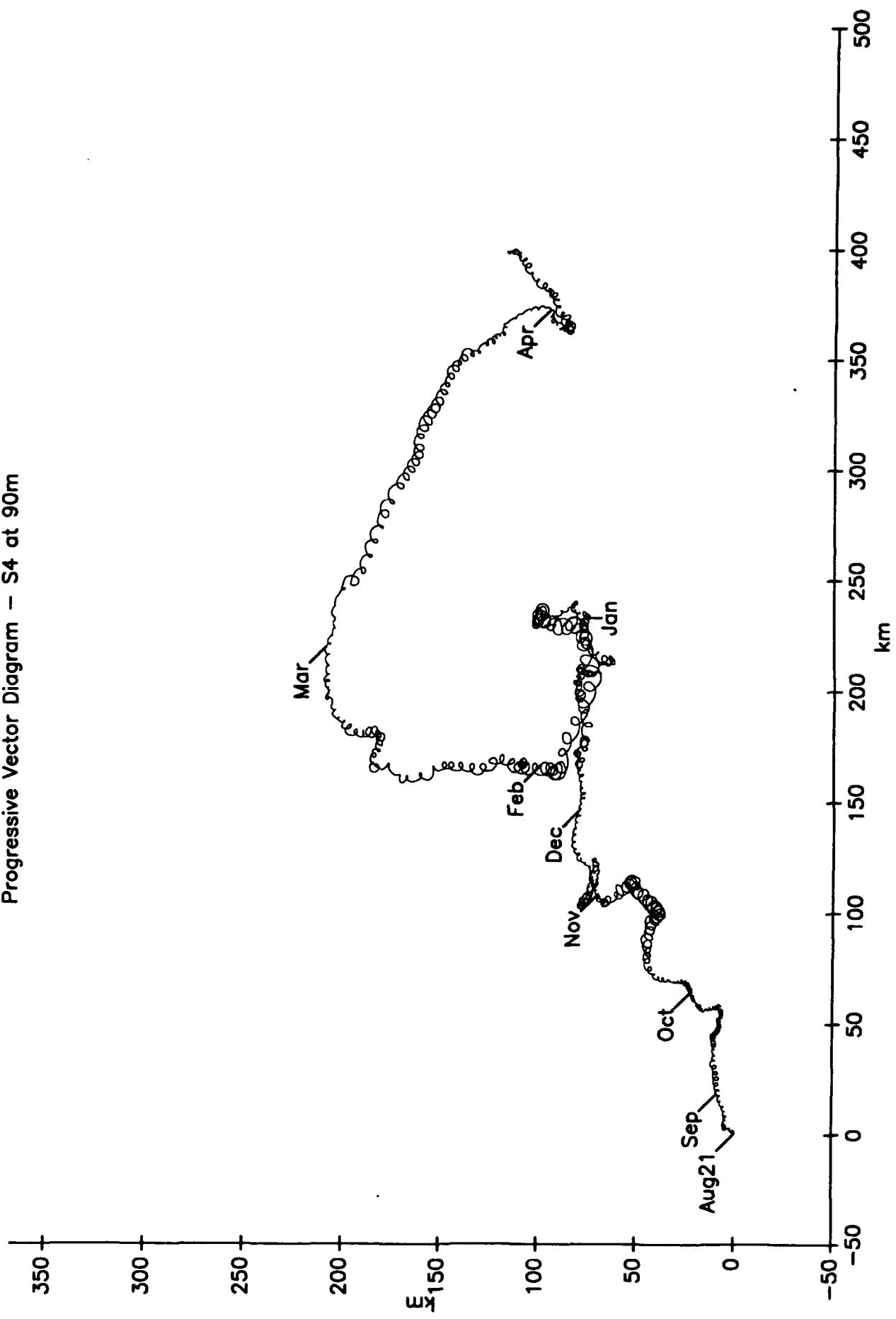


Progressive Vector Diagram – VMCM at 80m

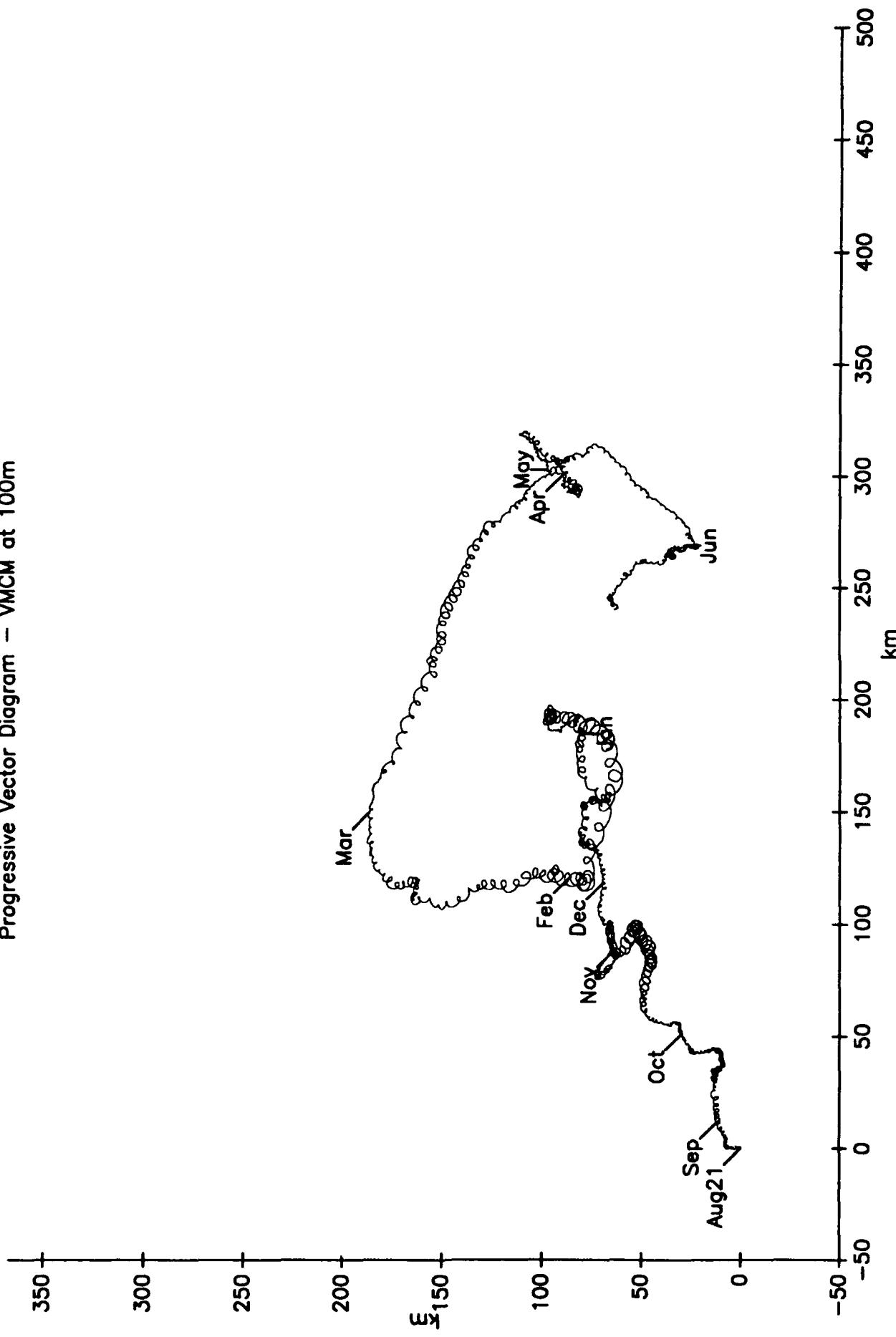
91



Progressive Vector Diagram – S4 at 90m

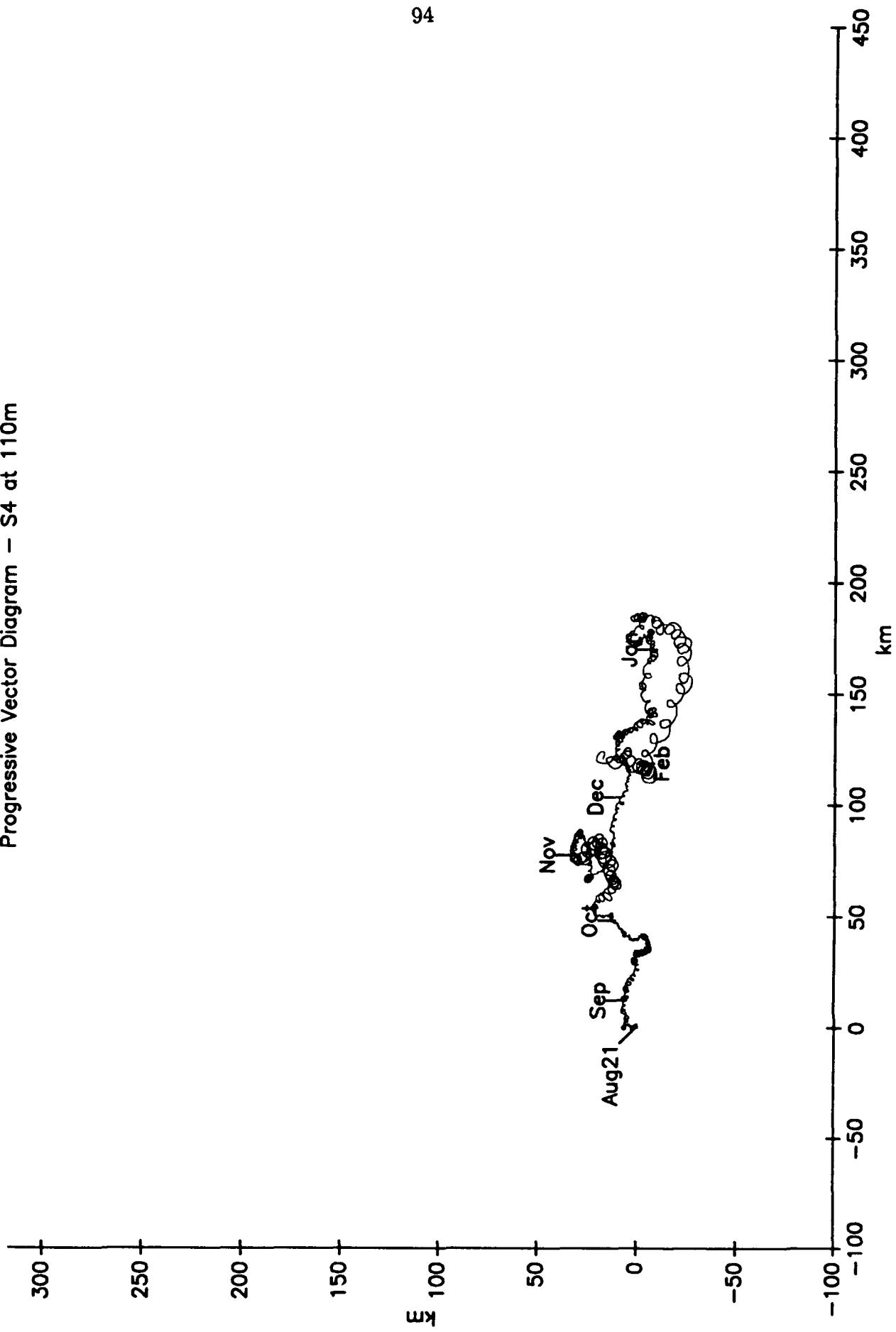


Progressive Vector Diagram – VMCM at 100m

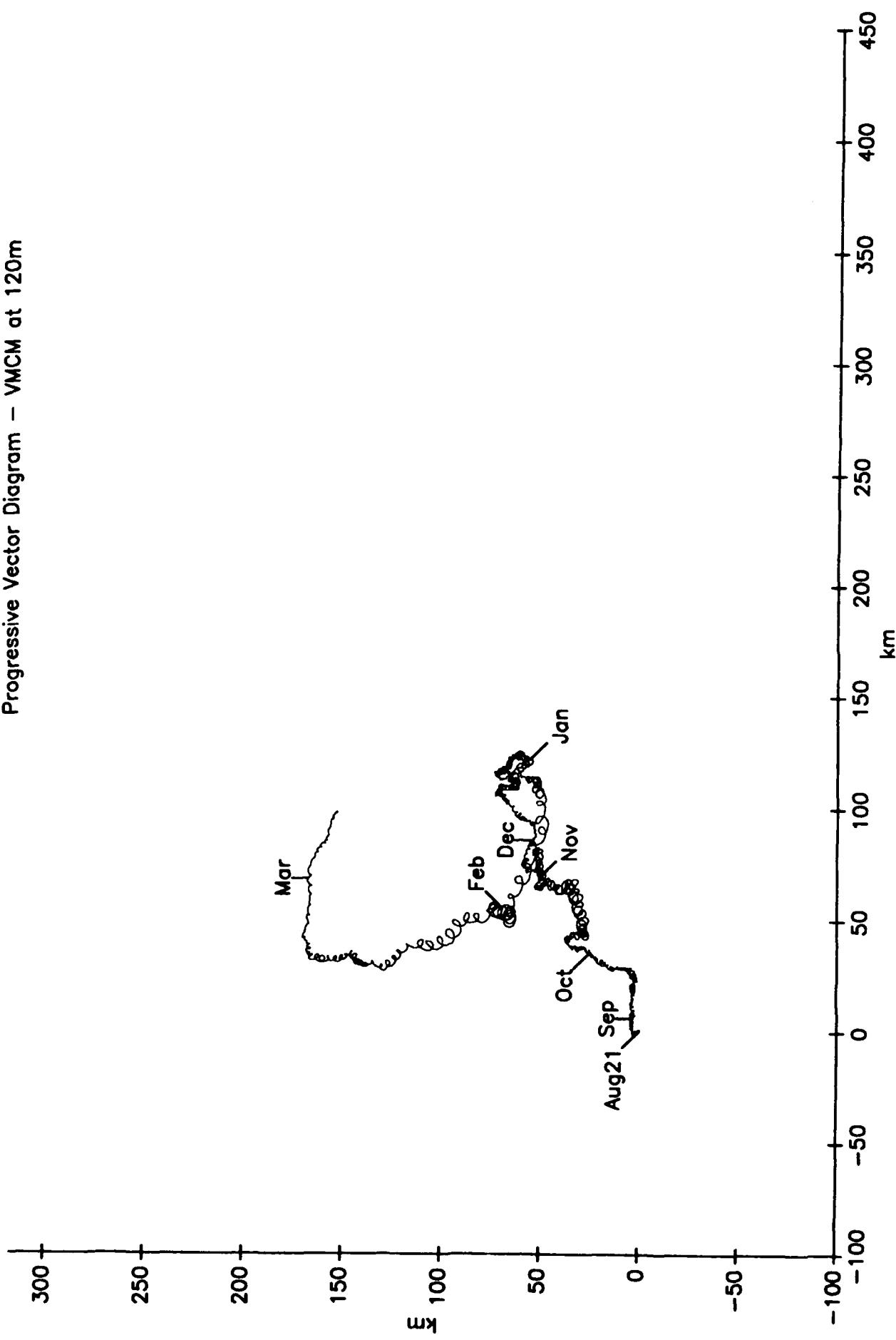


Progressive Vector Diagram – S4 at 110m

94

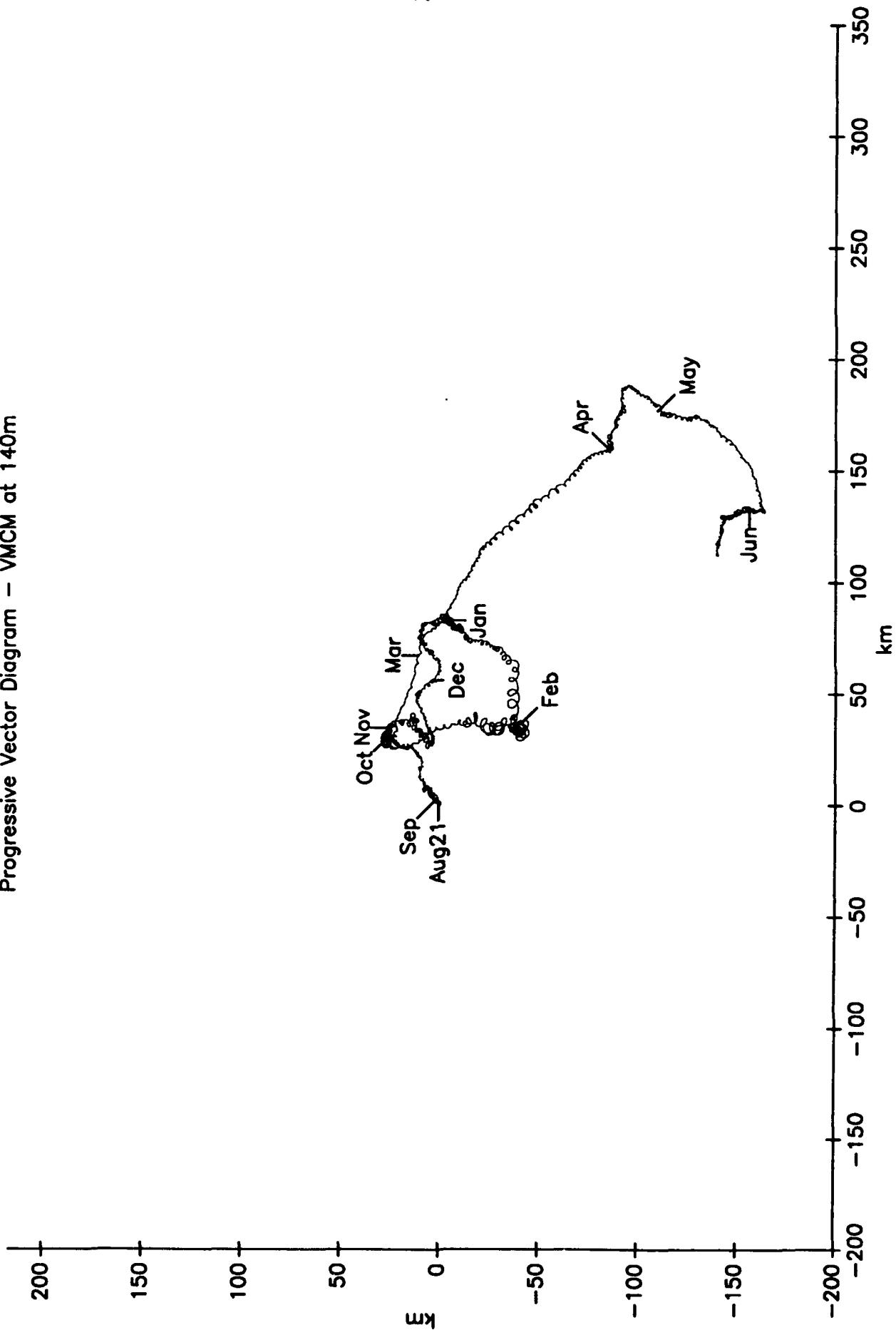


Progressive Vector Diagram – VMCM at 120m



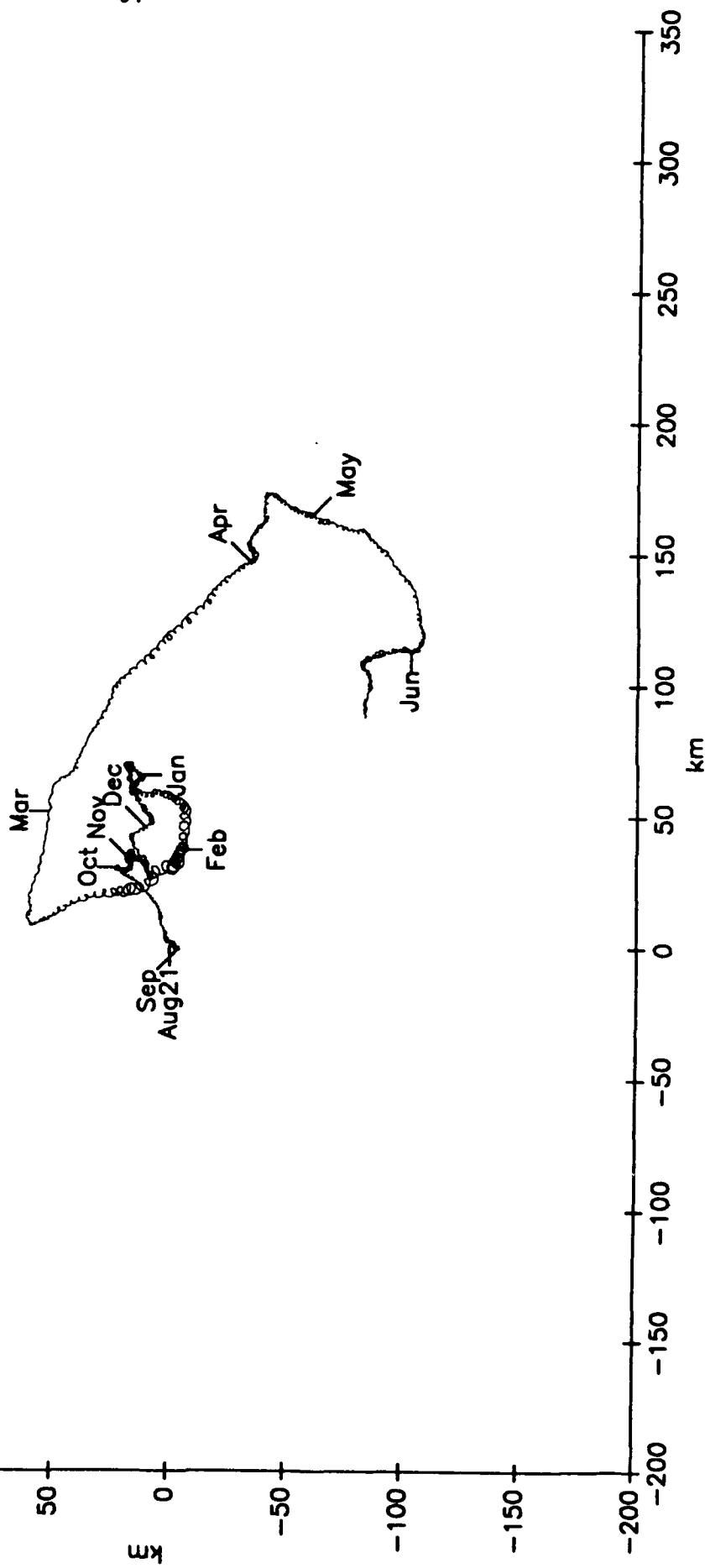
Progressive Vector Diagram – VMCM at 140m

96



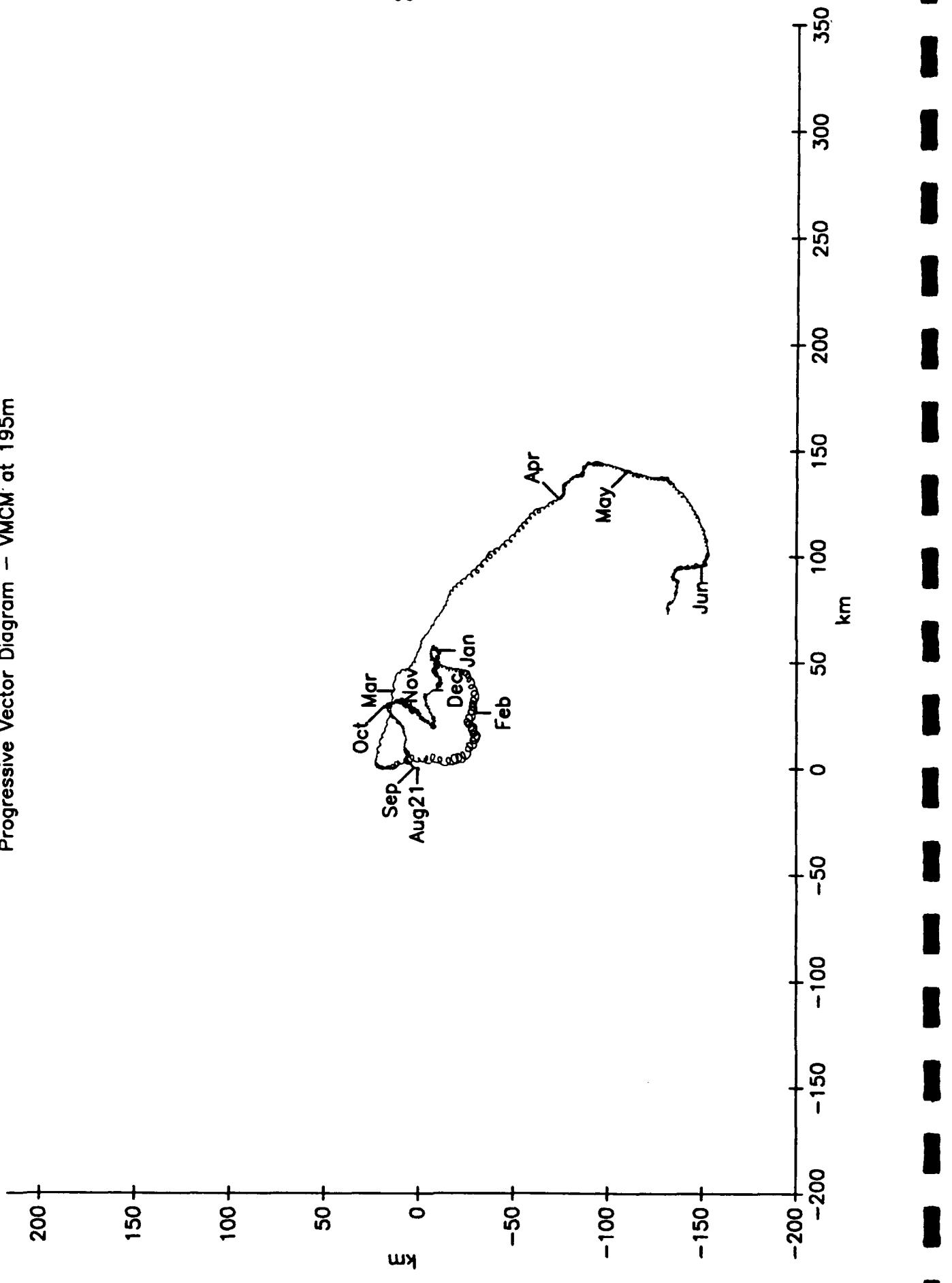
Progressive Vector Diagram – VMCM at 160m

97

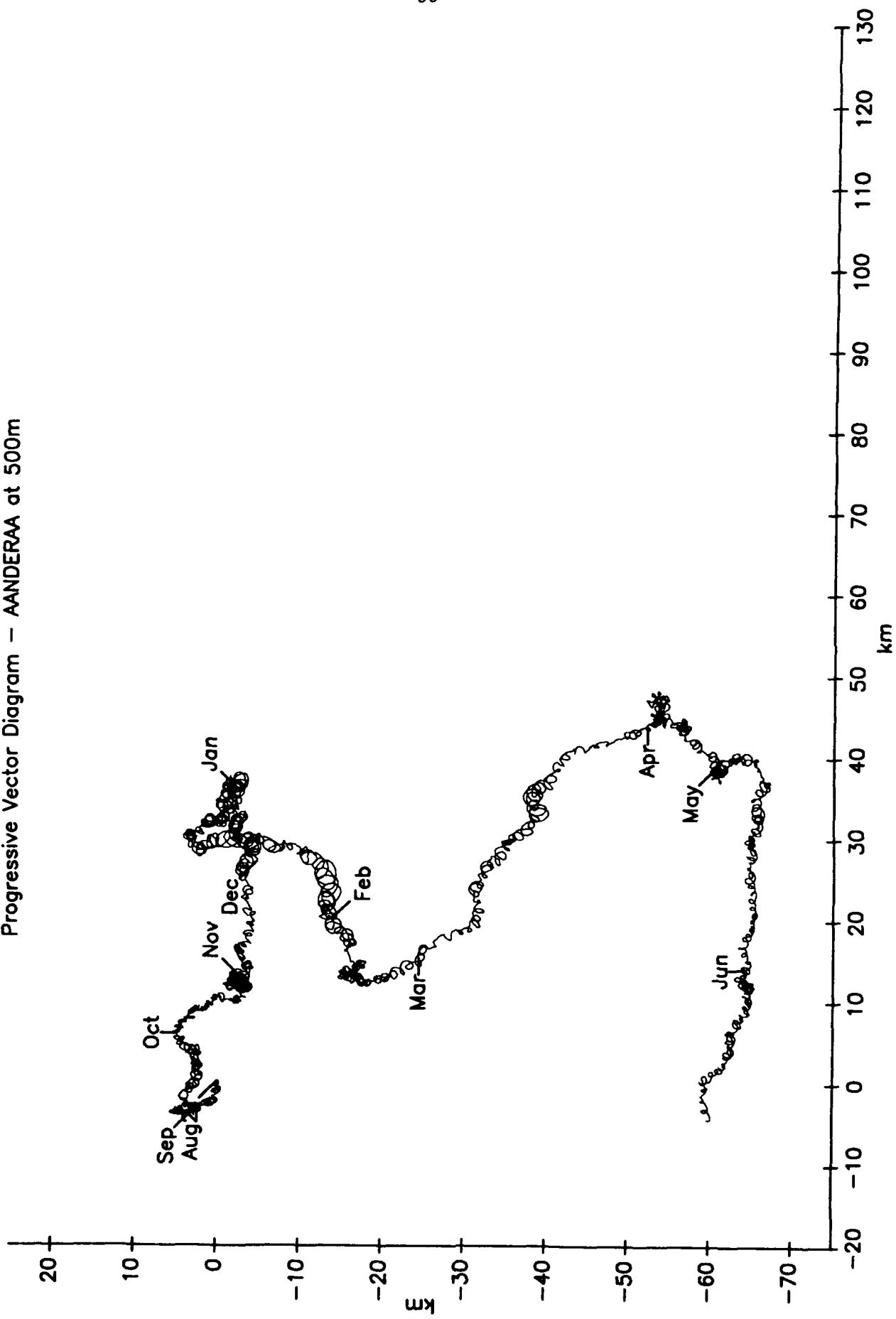


Progressive Vector Diagram – VMCM at 195m

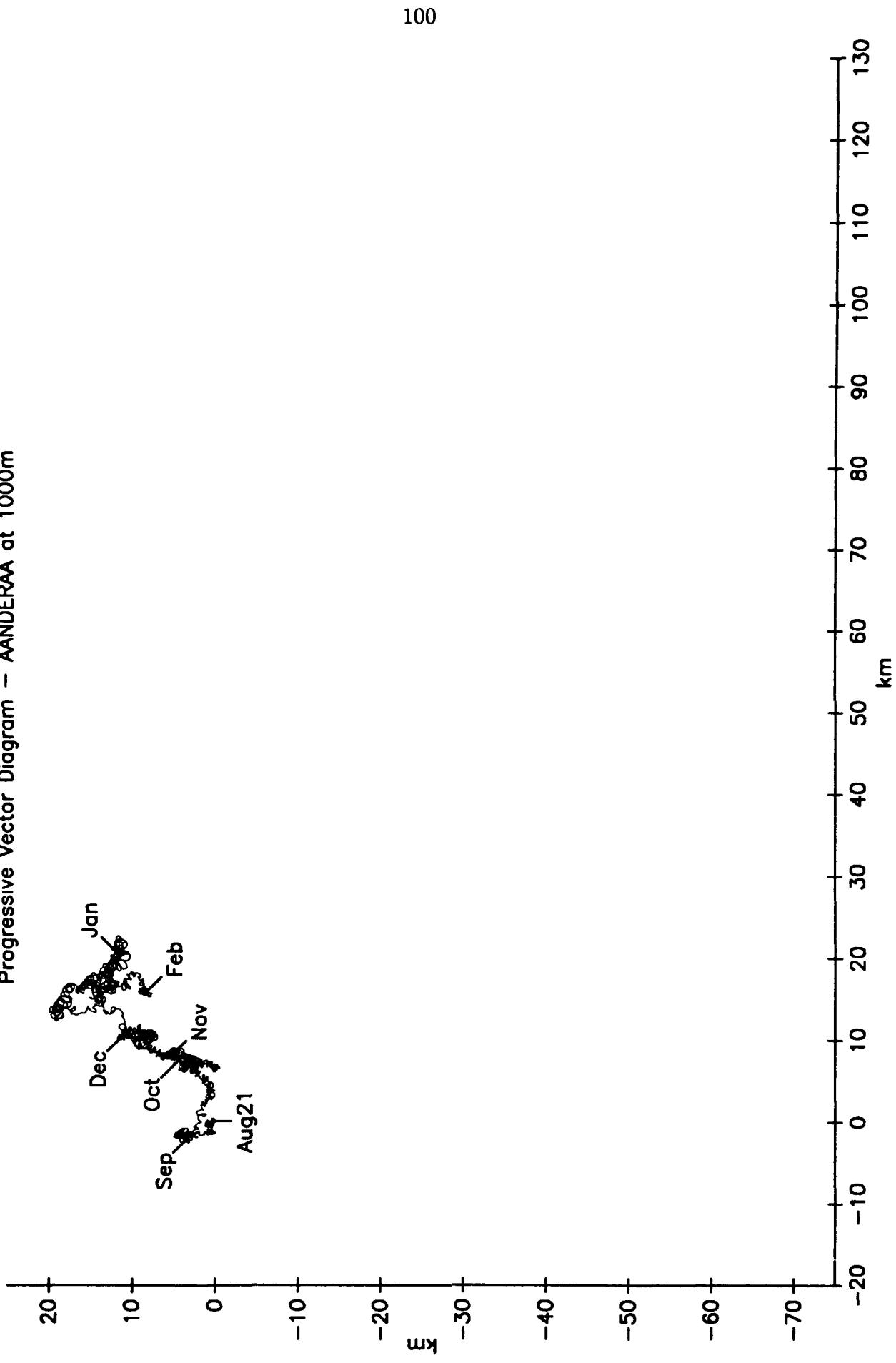
98



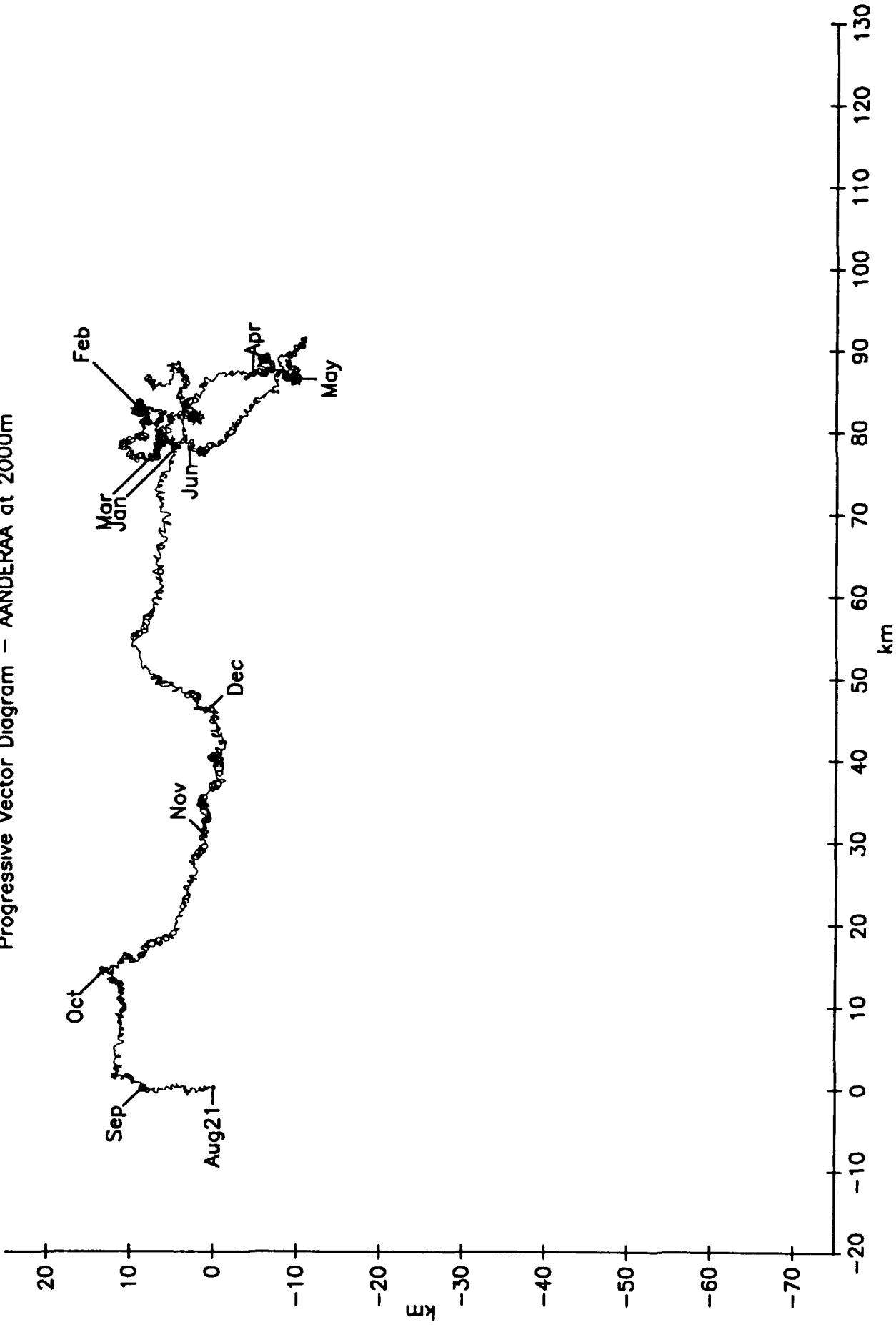
Progressive Vector Diagram - ANDERAA at 500m



Progressive Vector Diagram – AANDERAA at 1000m

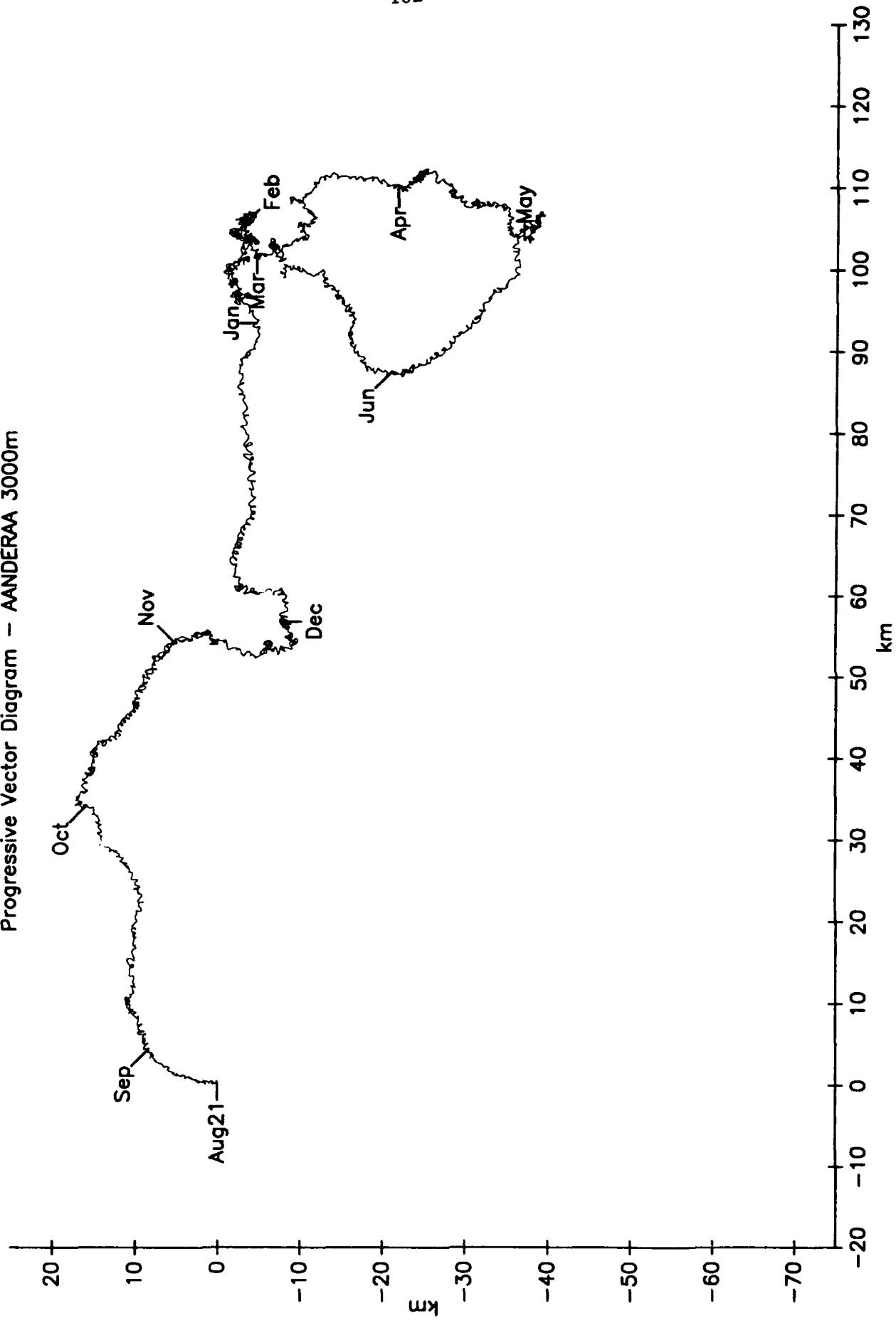


Progressive Vector Diagram - AANDERAA at 2000m



Progressive Vector Diagram - AANDERAA 3000m

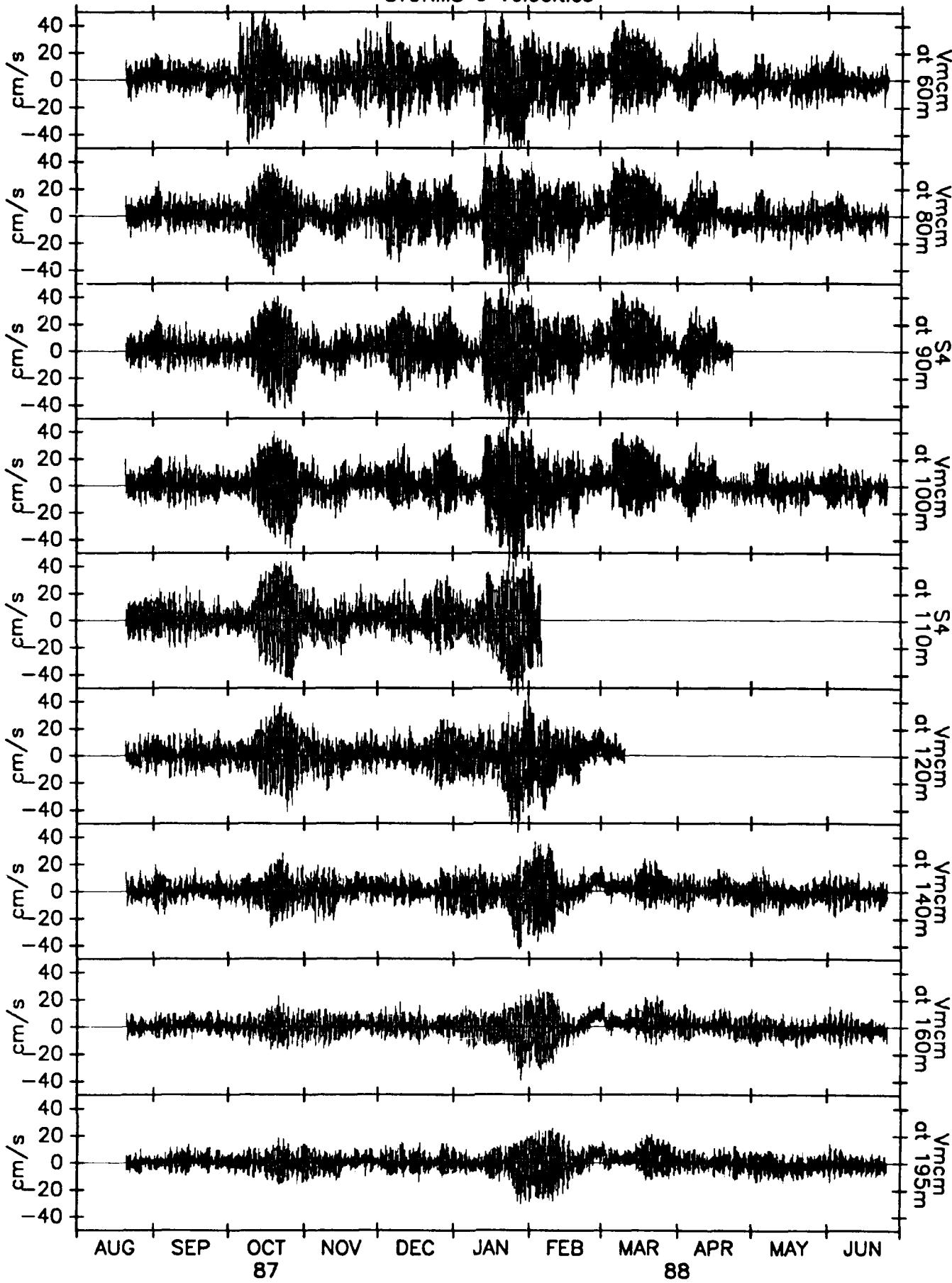
102

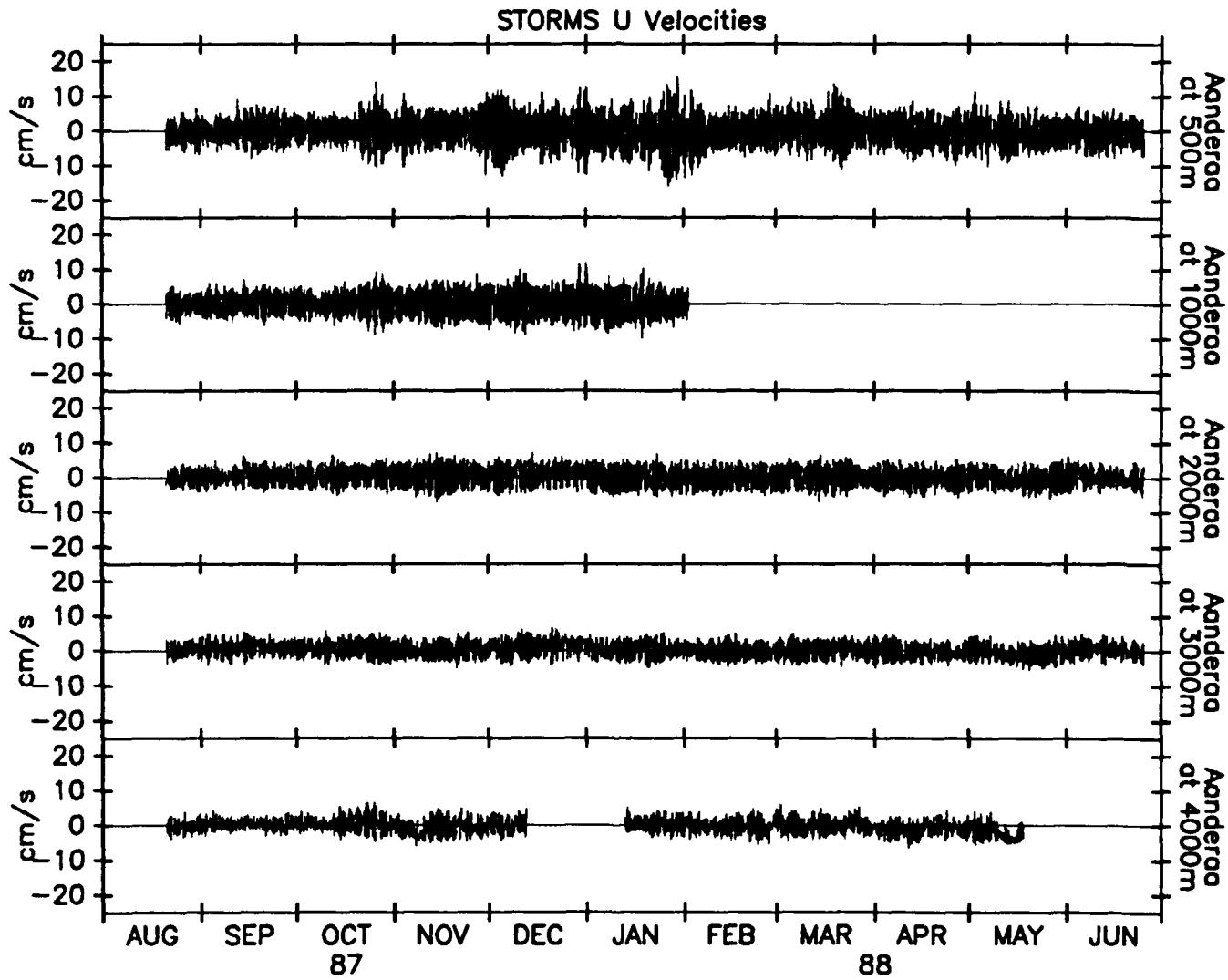


TIME SERIES OF VELOCITY: UNFILTERED

On the following 4 pages are the u and v components of velocity from VMCMs at 60, 80, 100, 120, 140, 160, and 195 m; S-4s at 90 and 110 m; and RCM-5s at 500, 1000, 2000, 3000 and 4000 m. Sampling interval is 15 minutes for VMCMs, 12 minutes for S-4s and 1 hour for RCM-5s. Note that the velocity scale changes by a factor of one-half for observations deeper than 500 m.

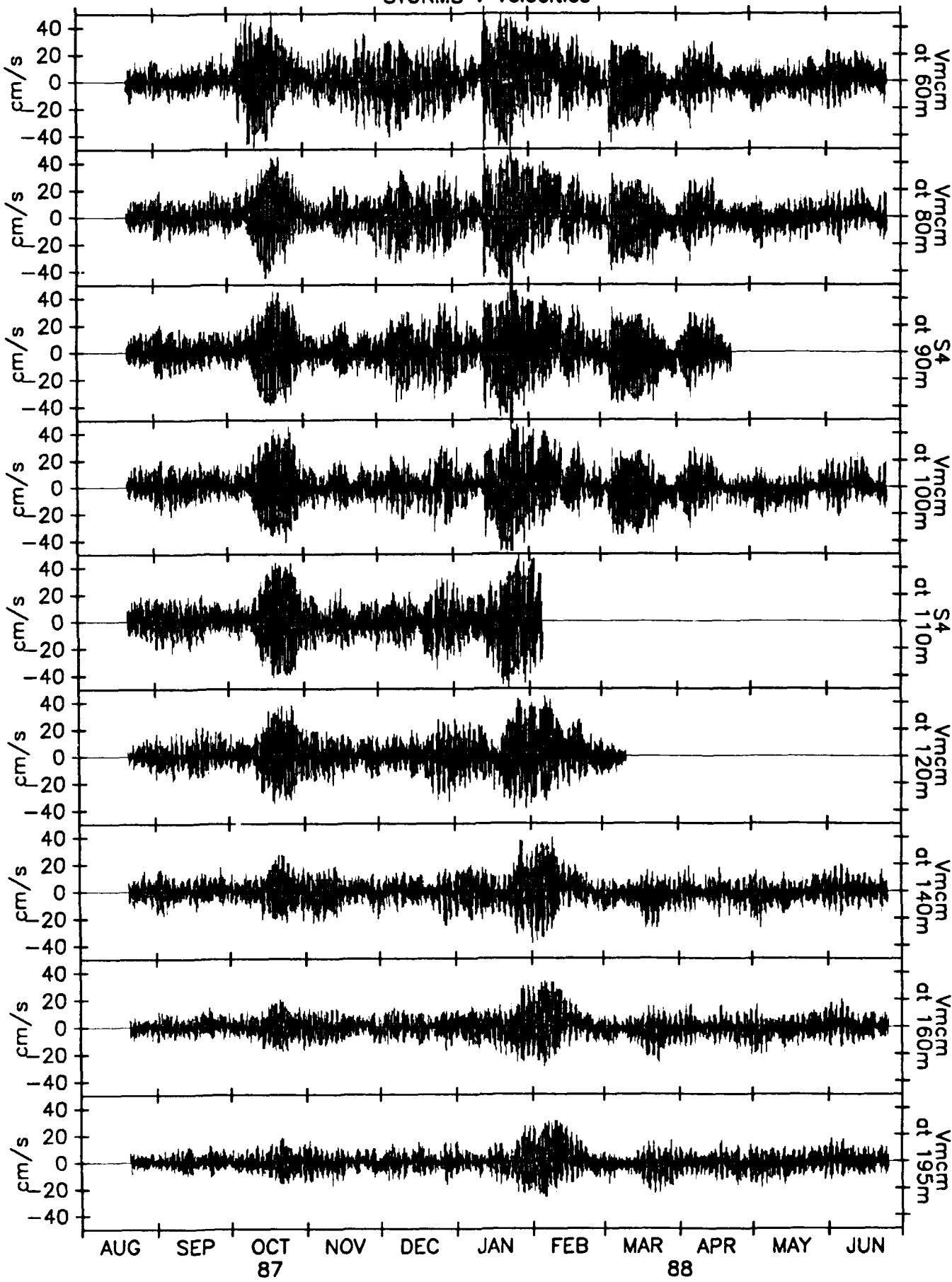
STORMS U Velocities

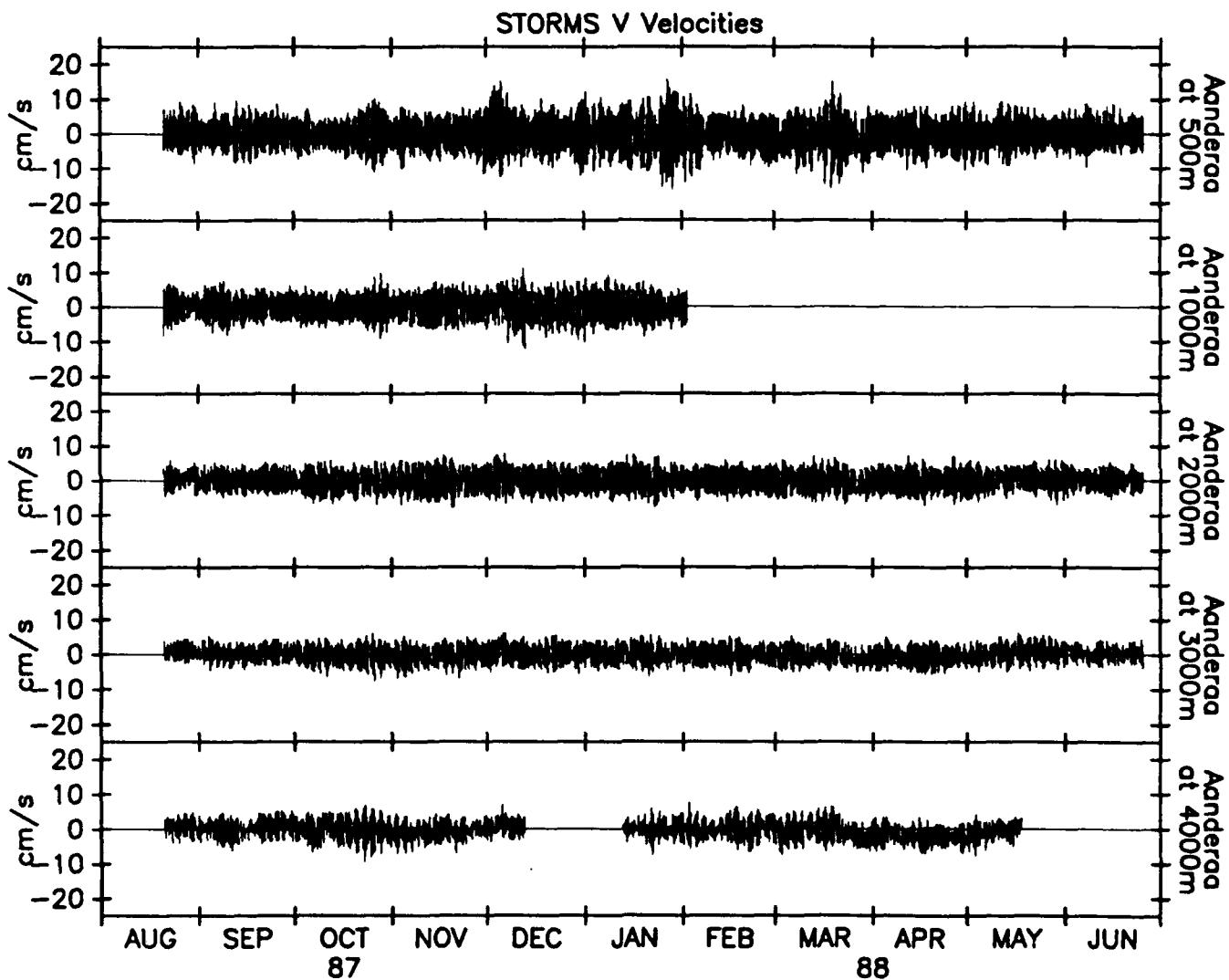




106

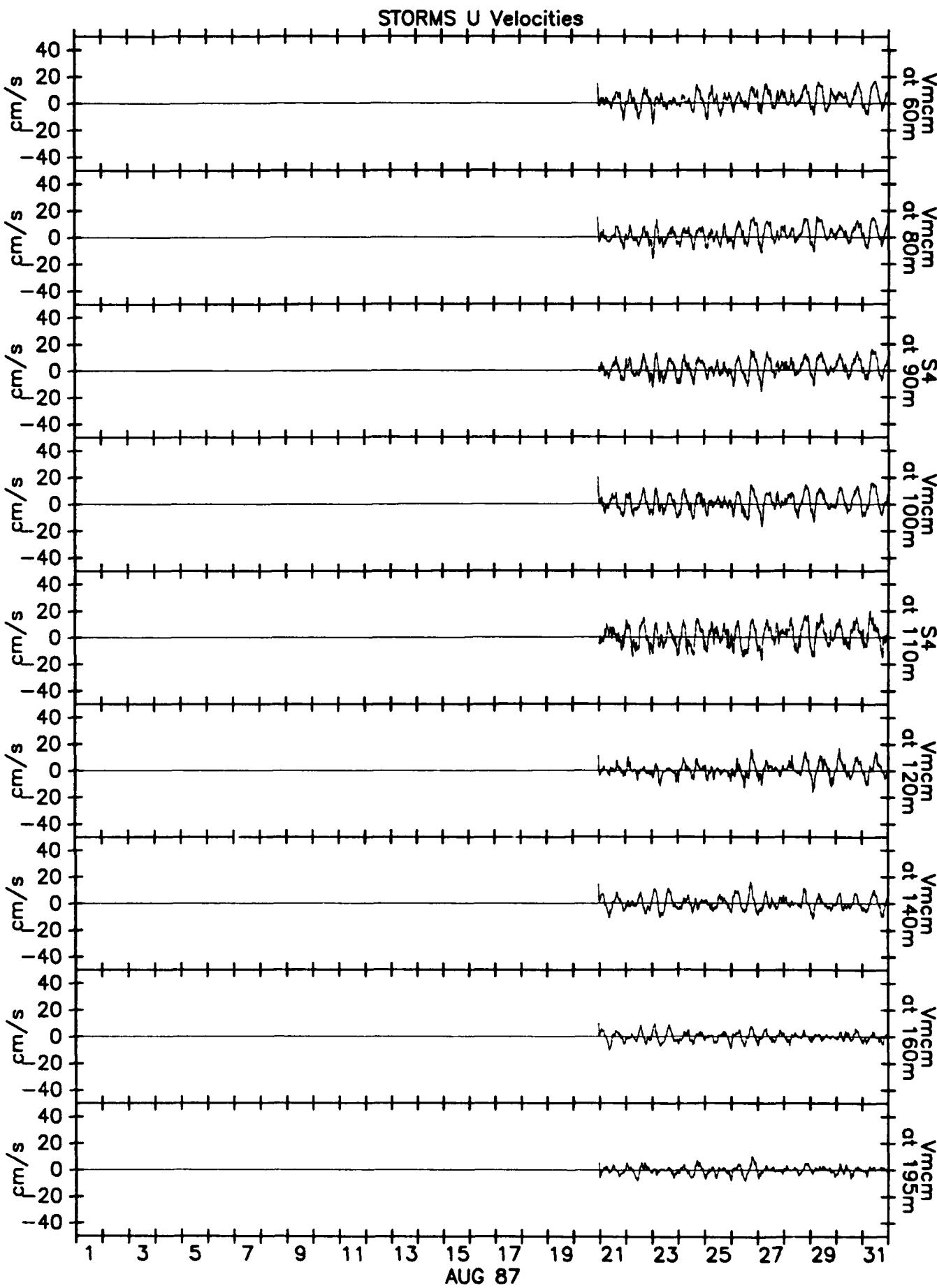
STORMS V Velocities

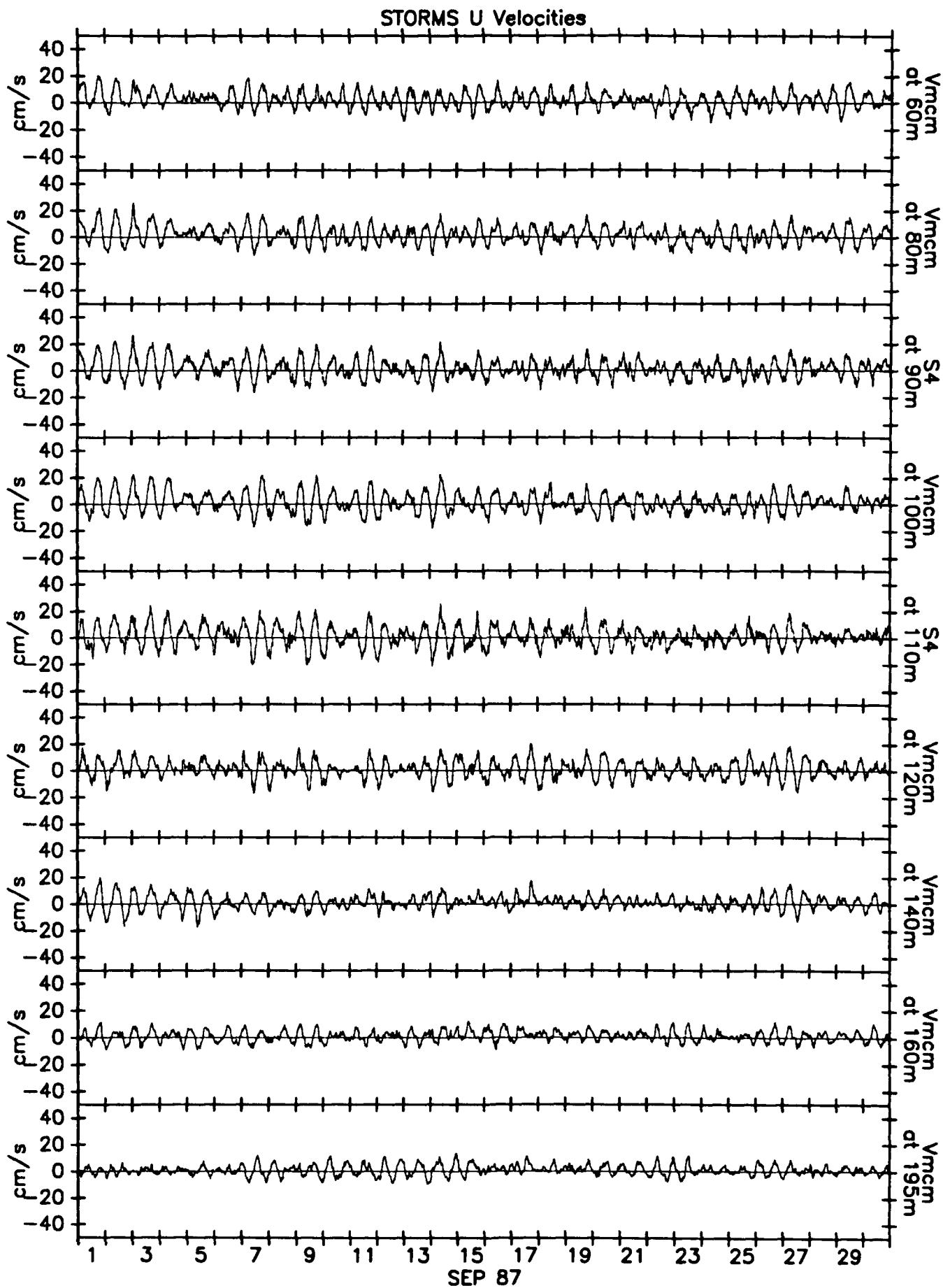




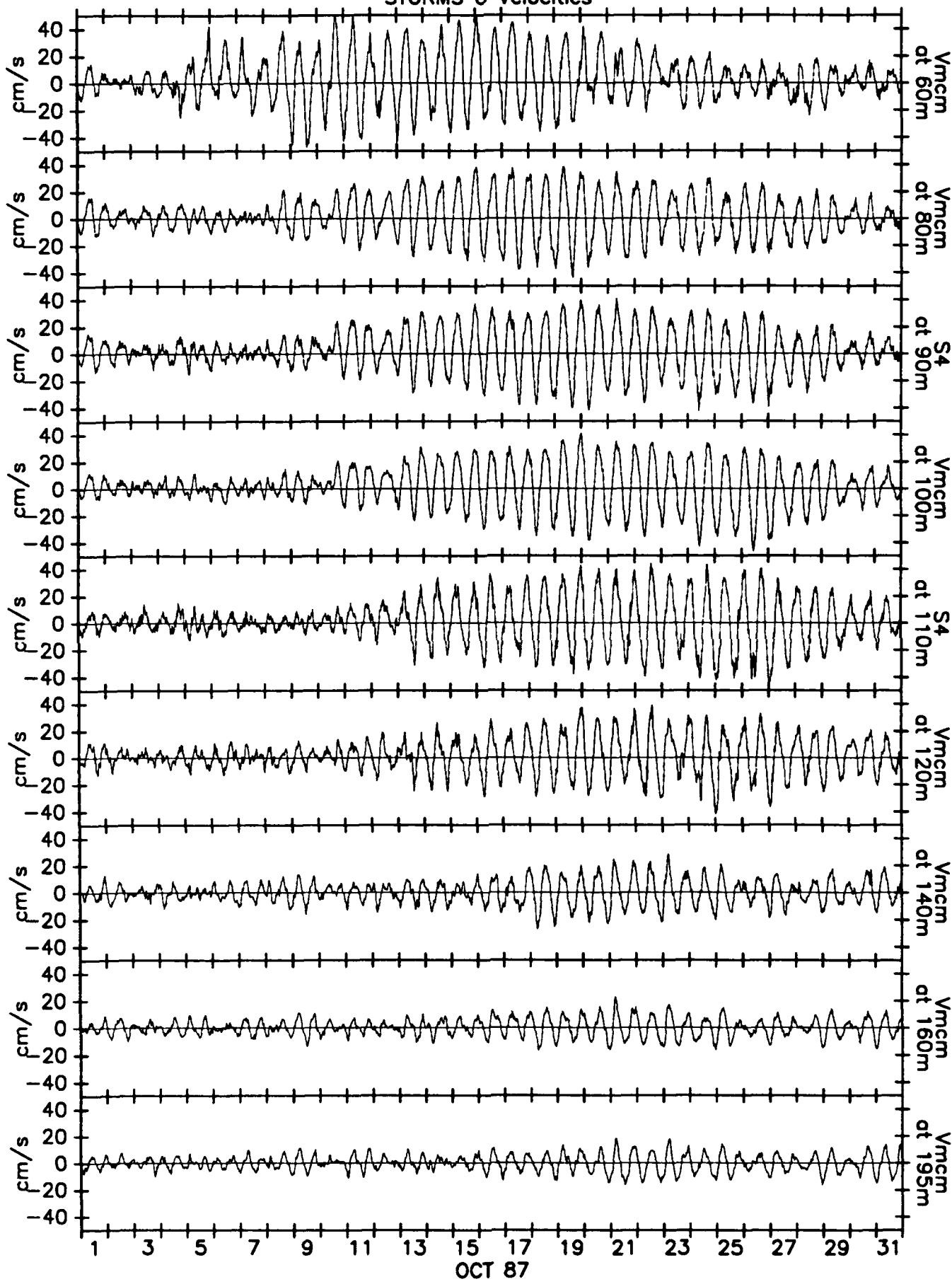
TIME SERIES OF VELOCITY: UNFILTERED

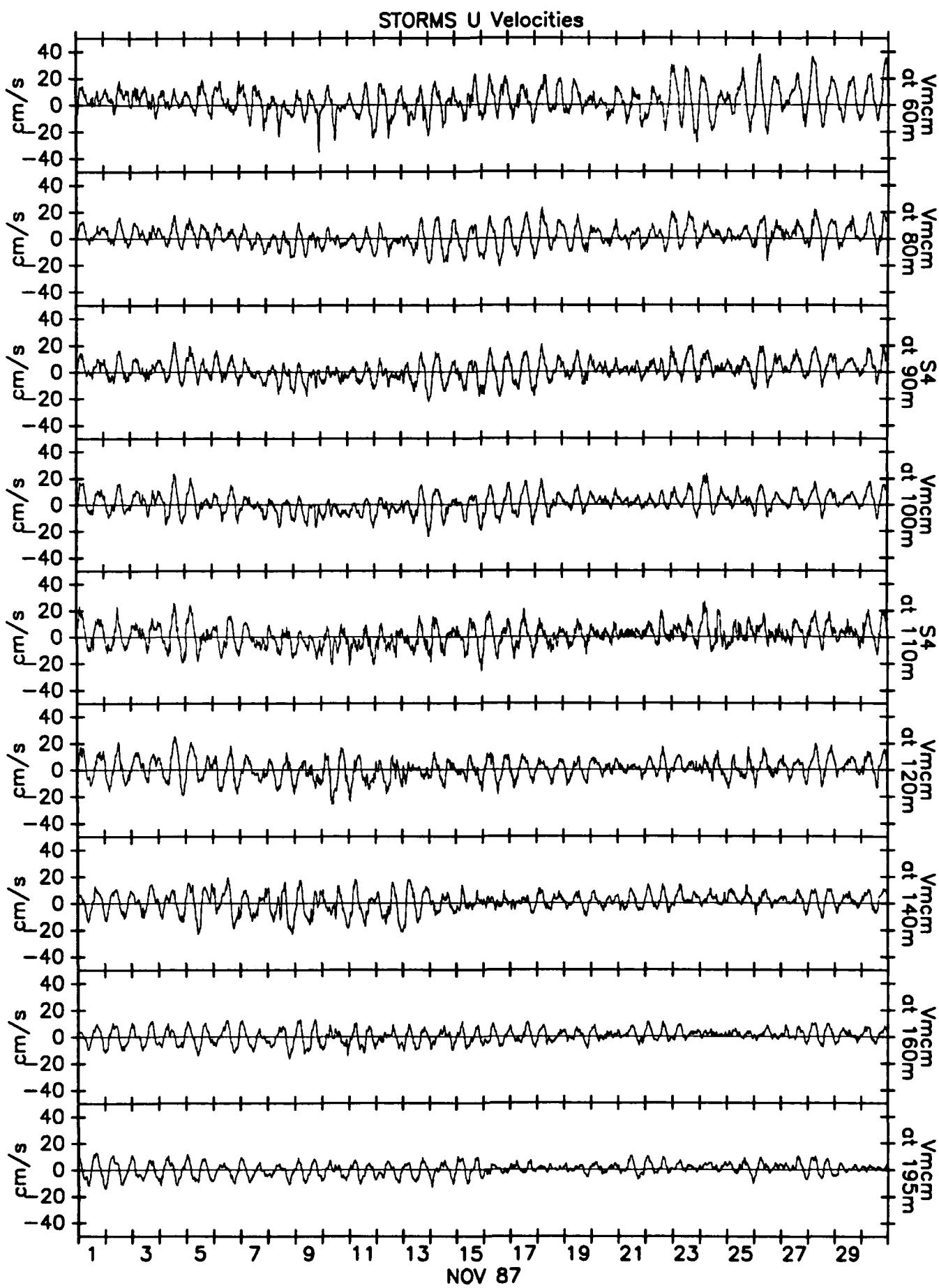
On the following 44 pages are the u and v components of velocity from VMCMs at 60, 80, 100, 120, 140, 160, and 195 m; S-4s at 90 and 110 m; and RCM-5s at 500, 1000, 2000, 3000 and 4000 m. One month is plotted per page. Sampling interval is 15 minutes for VMCMs, 12 minutes for S-4s and 1 hour for RCM-5s. Note that the velocity scale changes by a factor of one-half for observations deeper than 500 m.



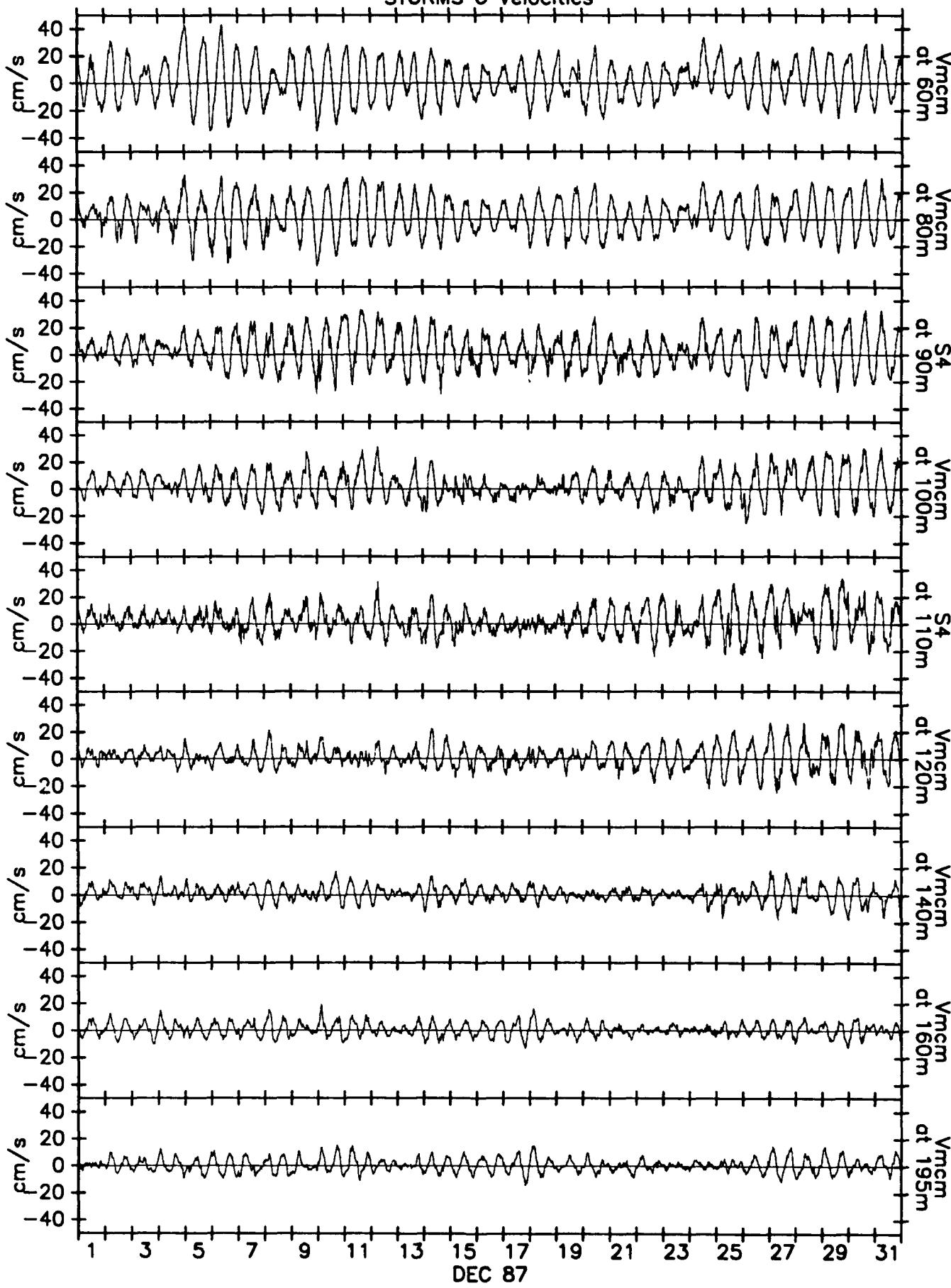


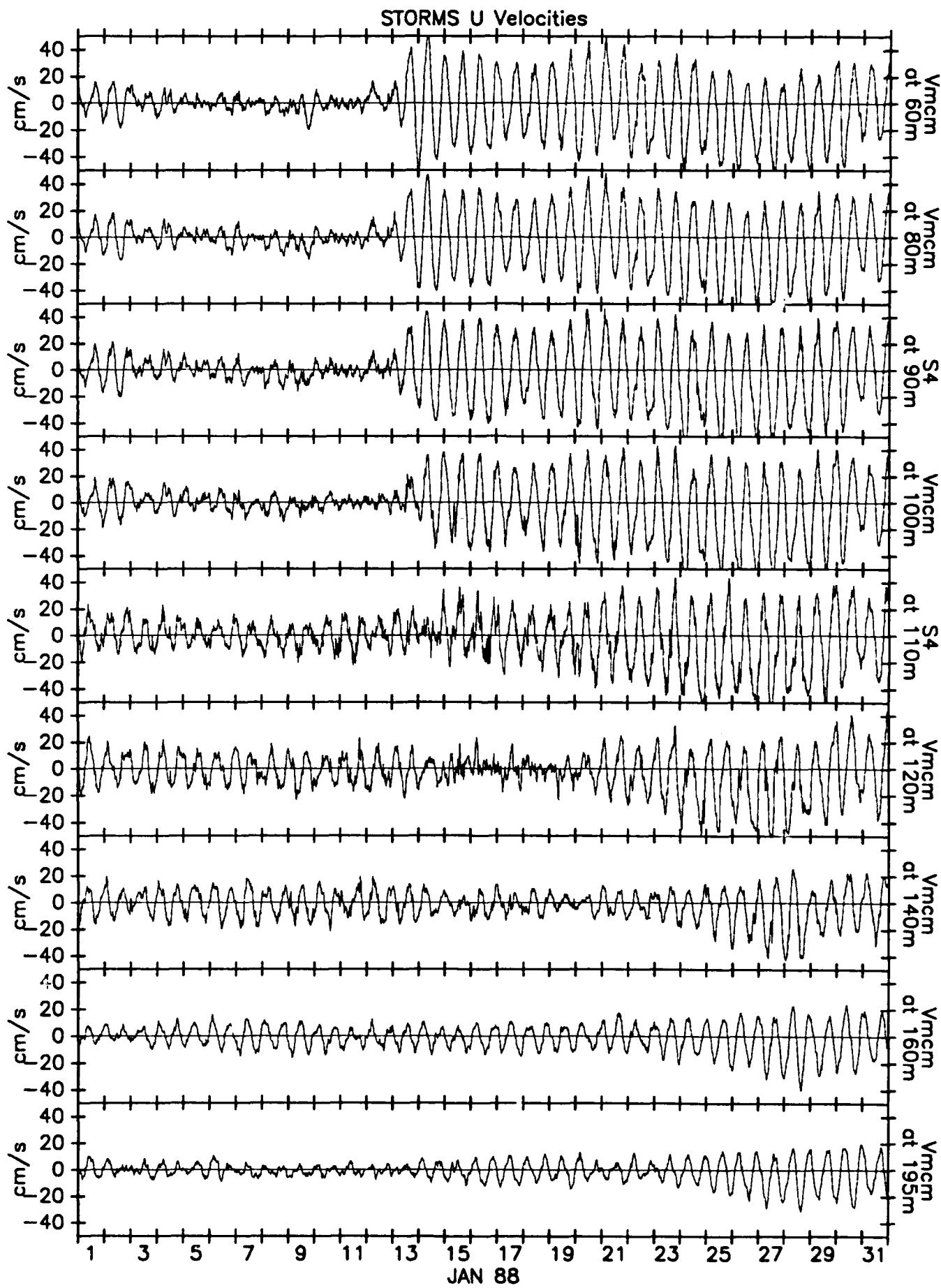
STORMS U Velocities

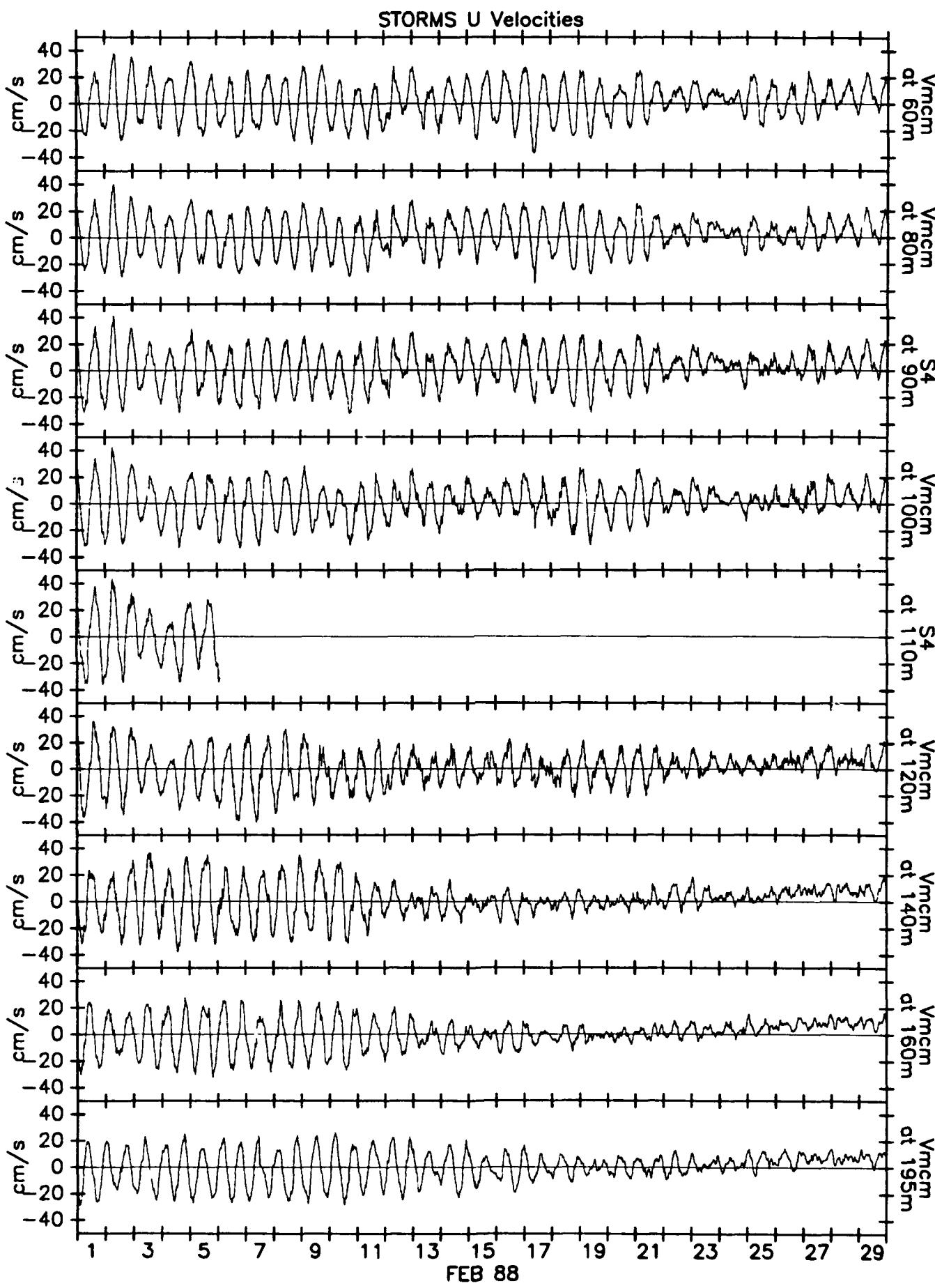


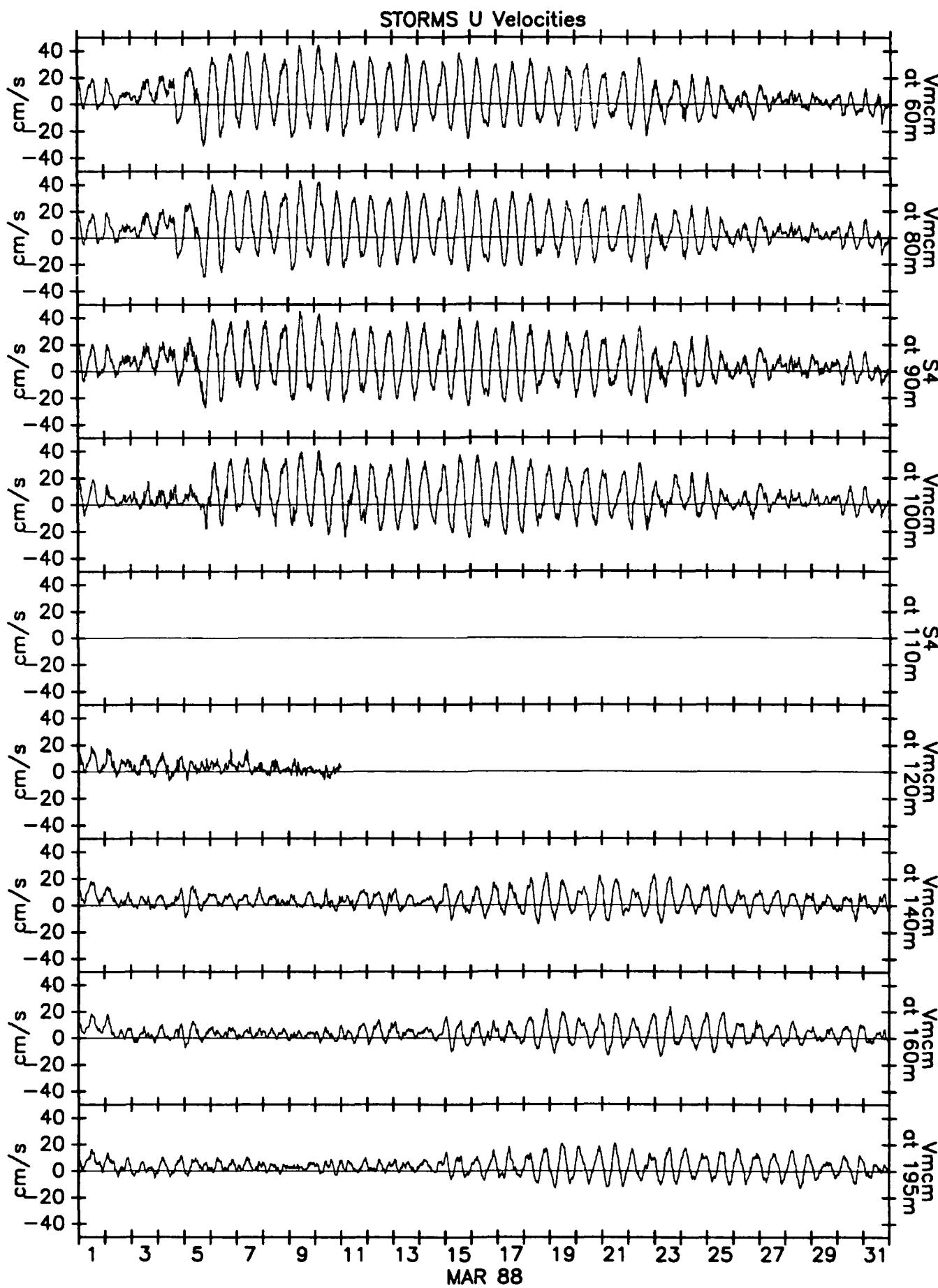


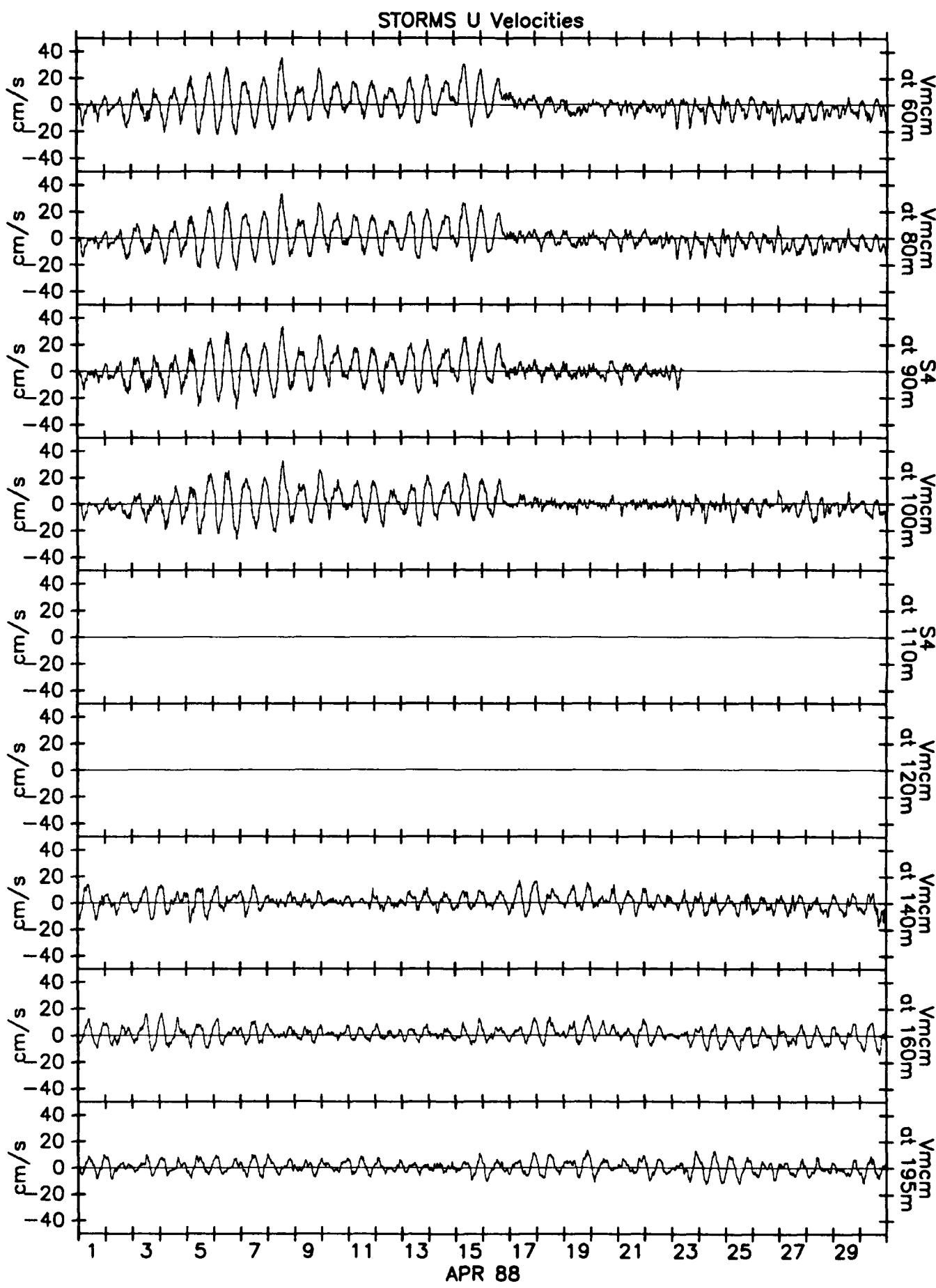
STORMS U Velocities

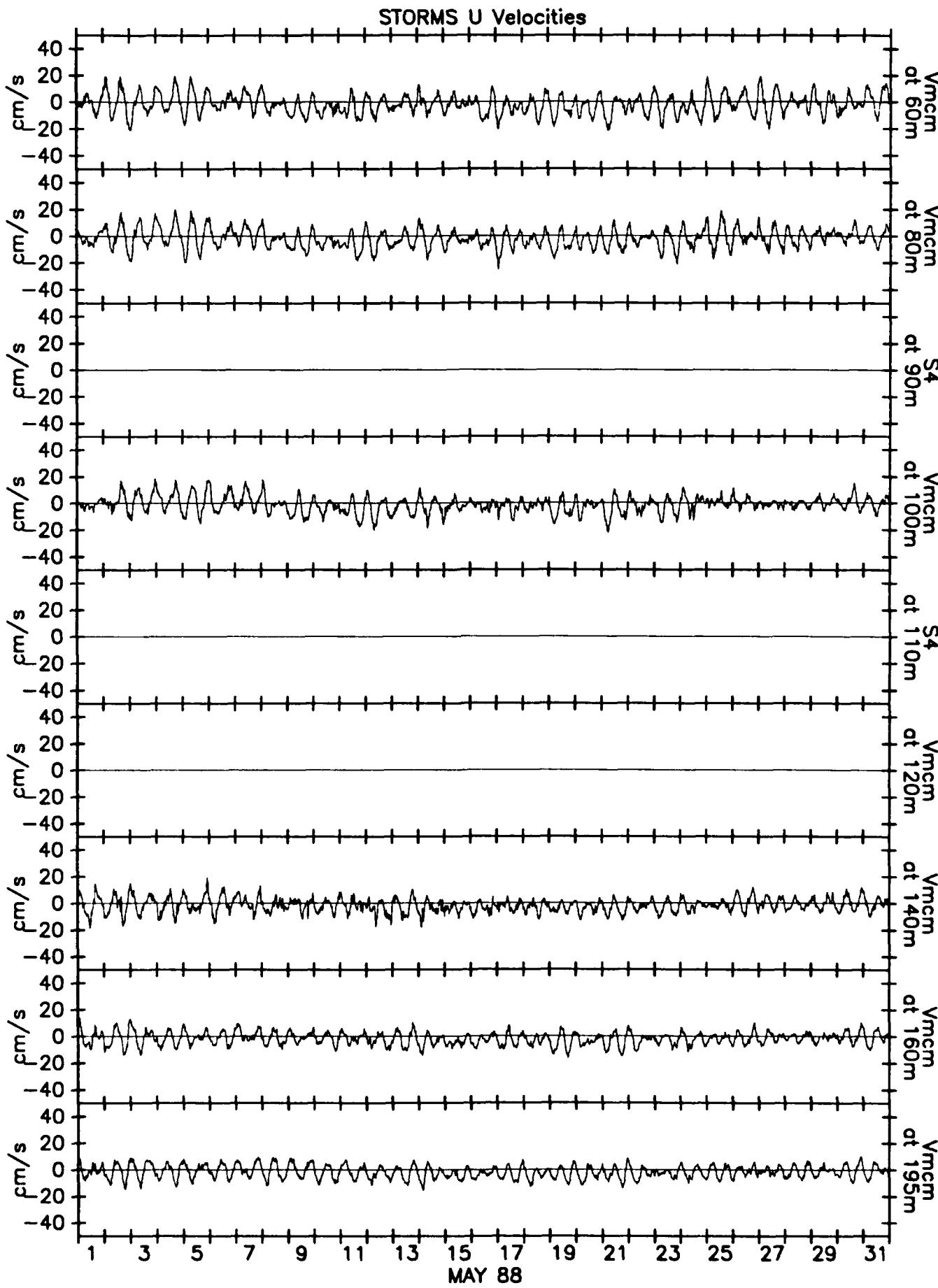


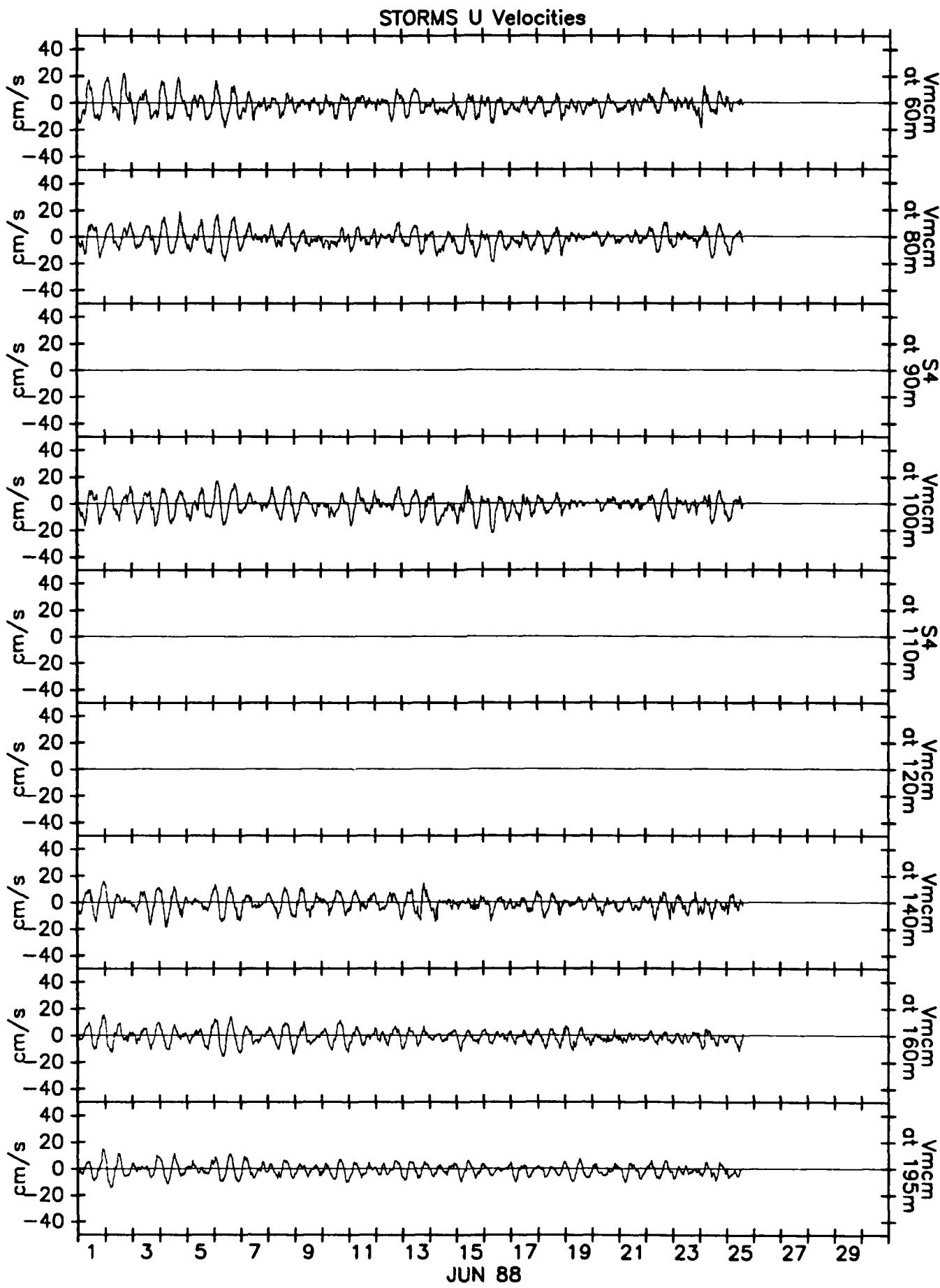


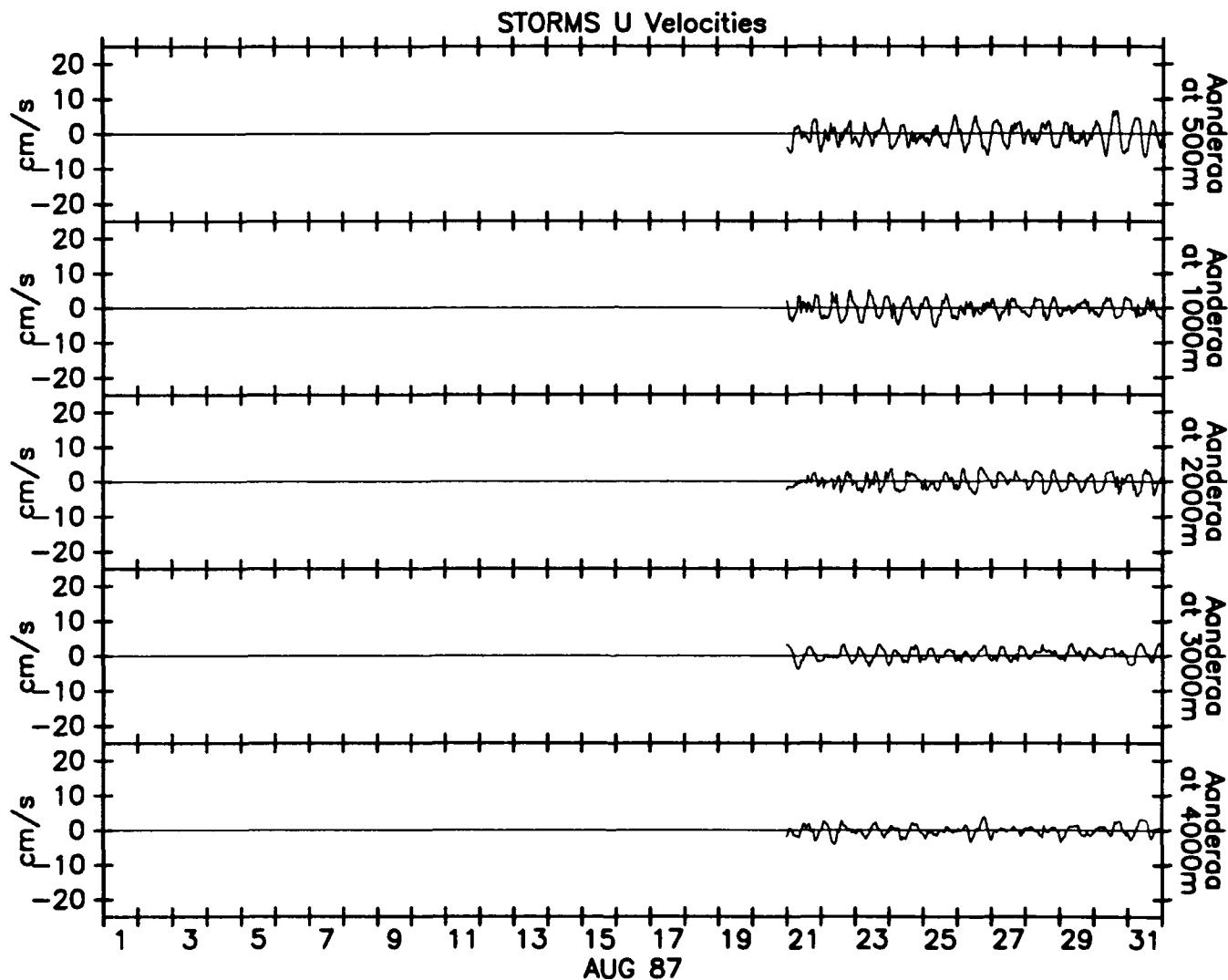


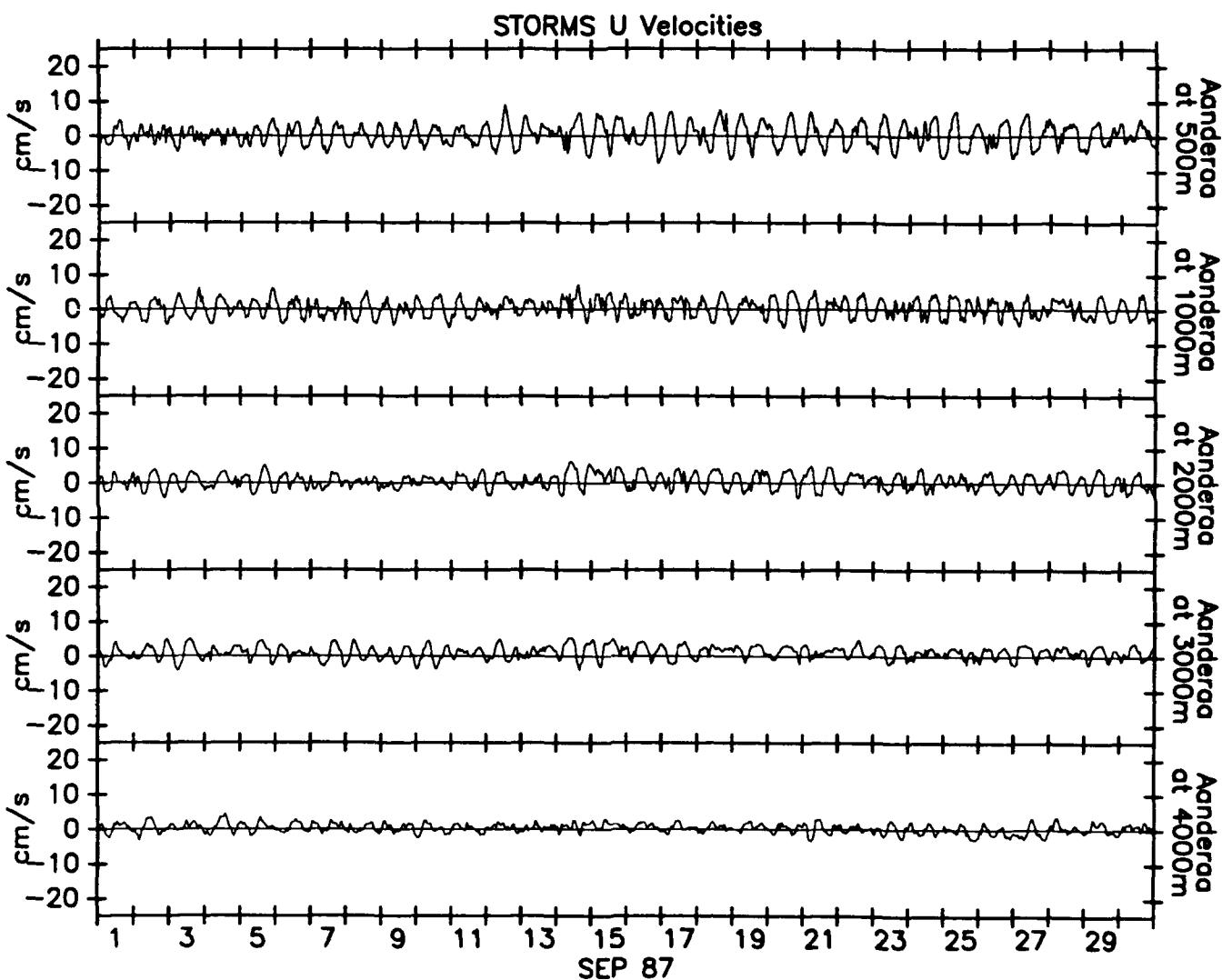


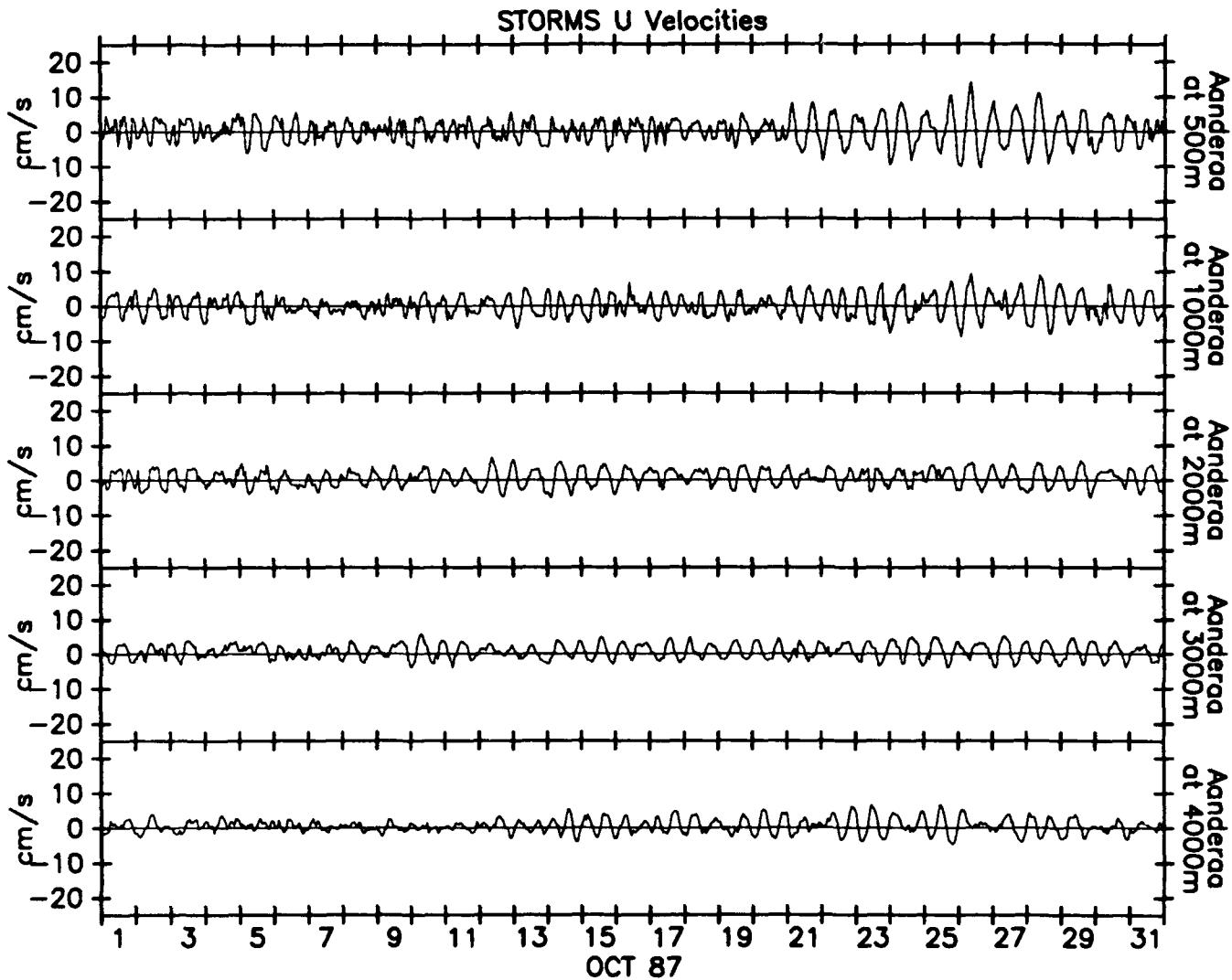


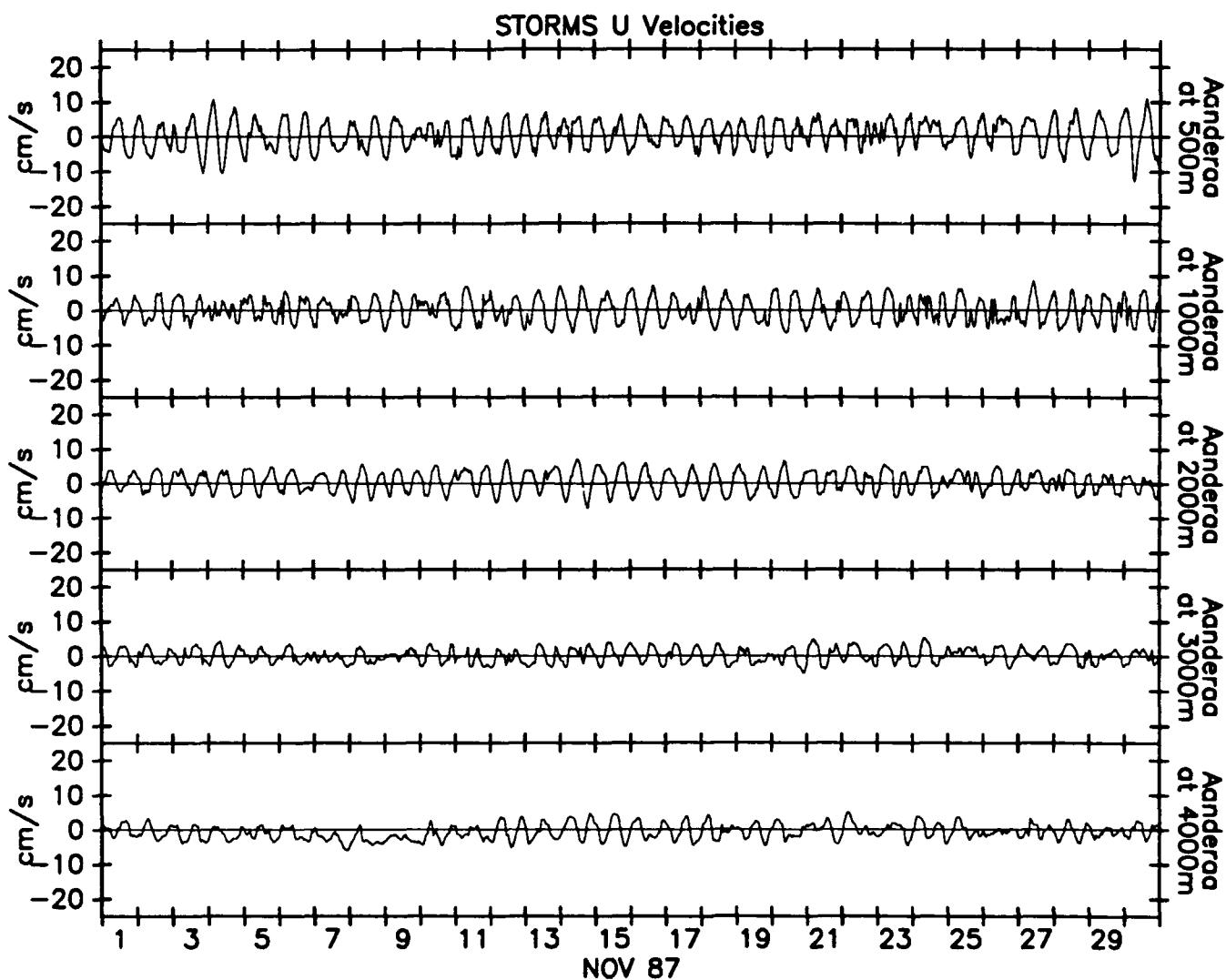


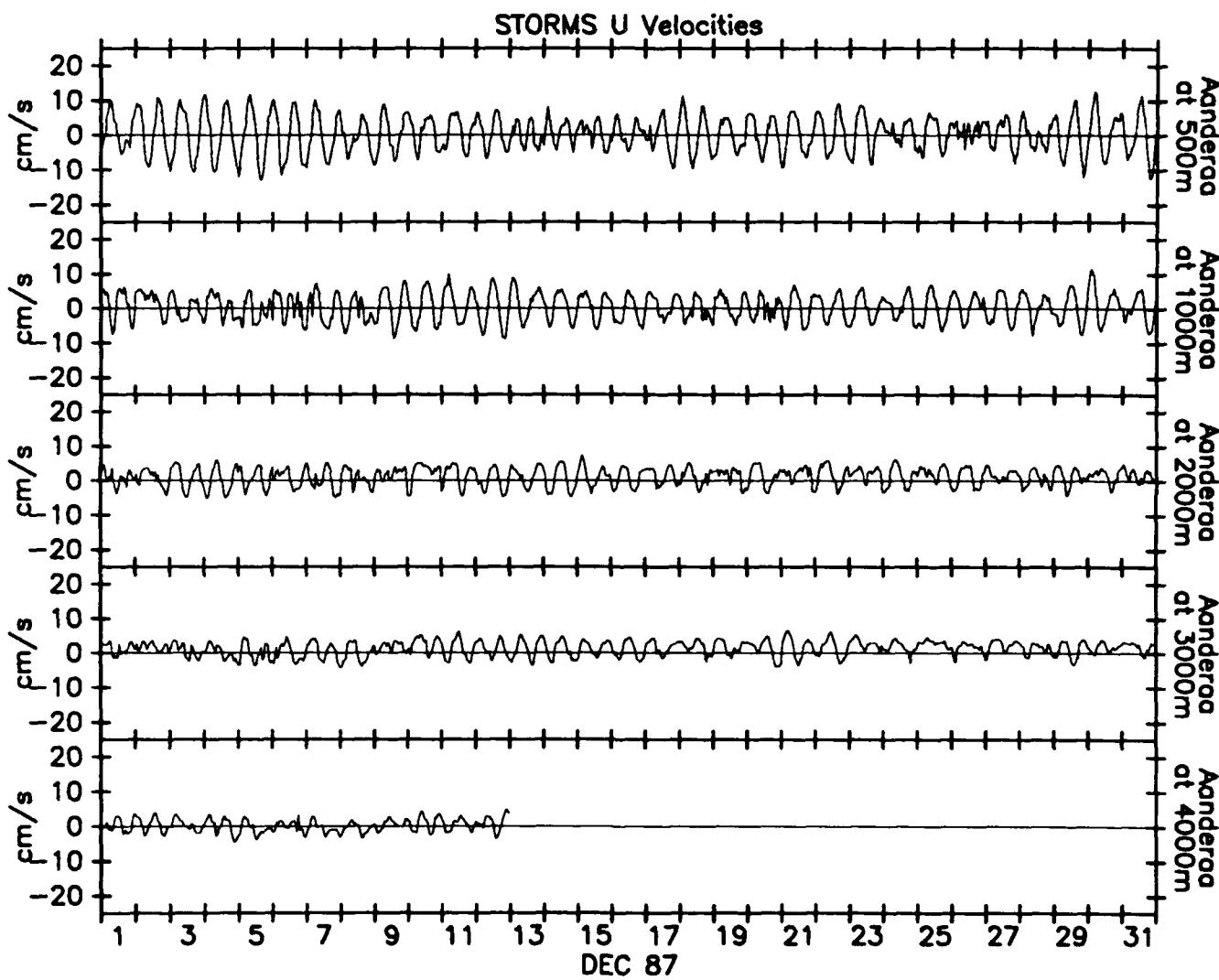


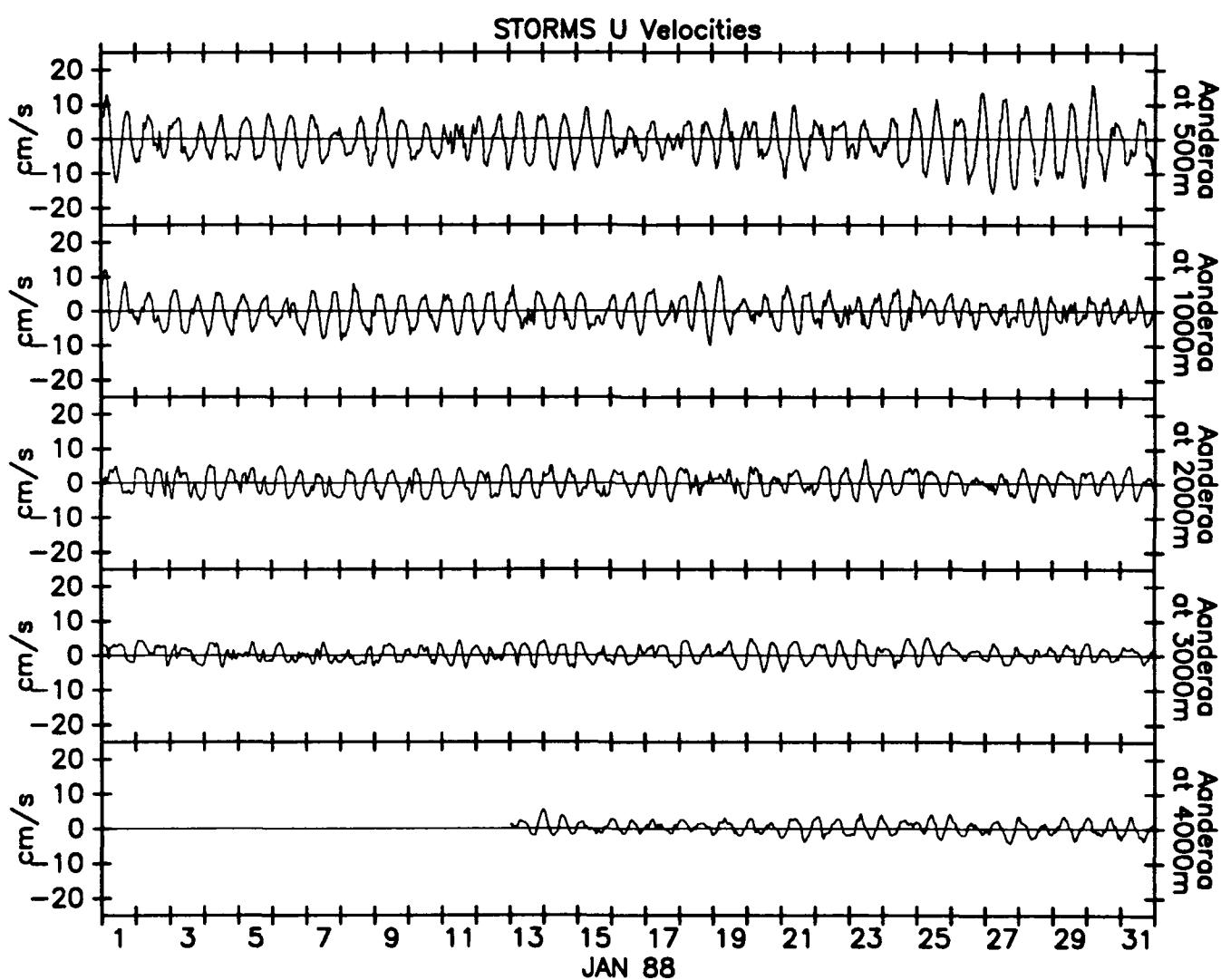


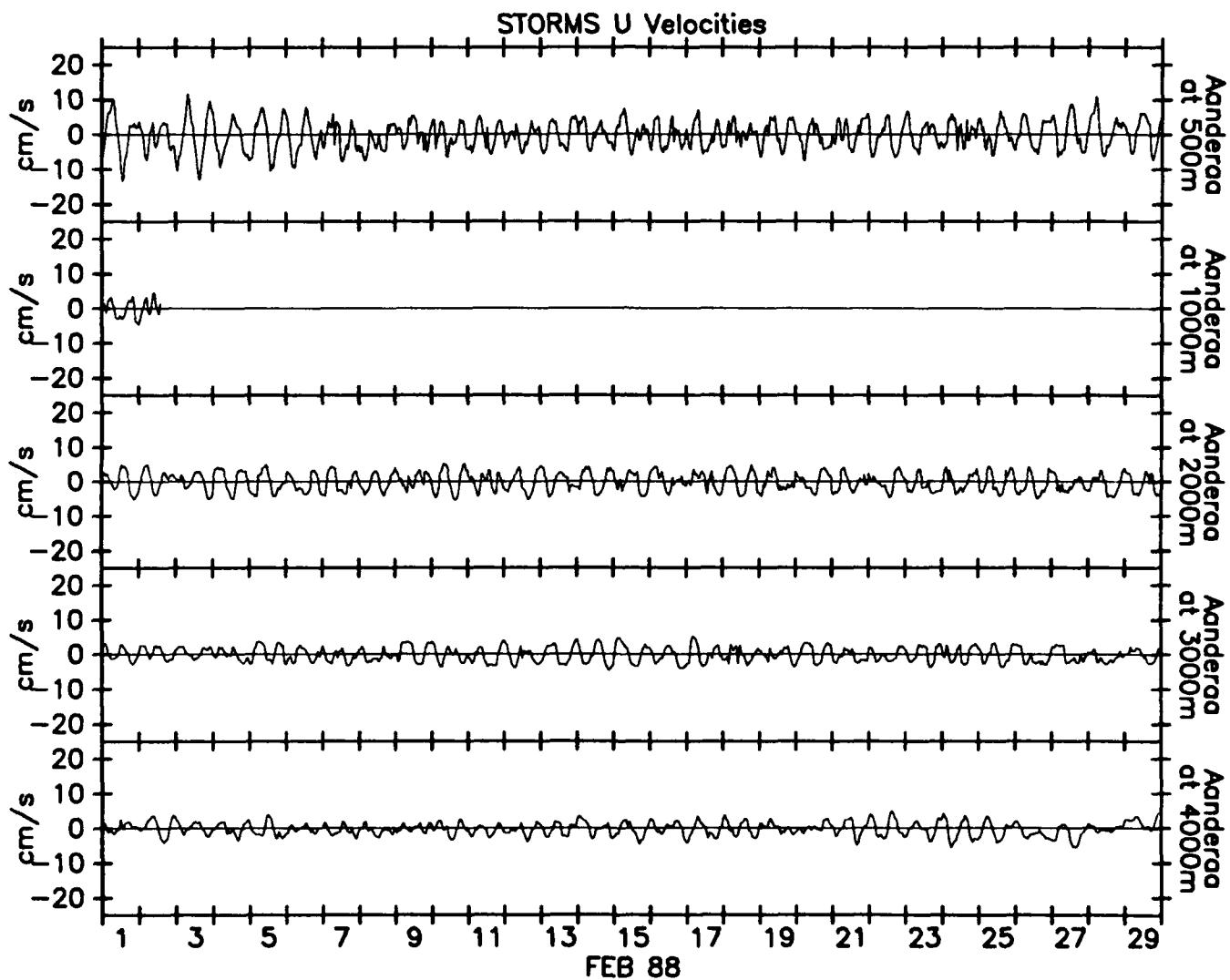


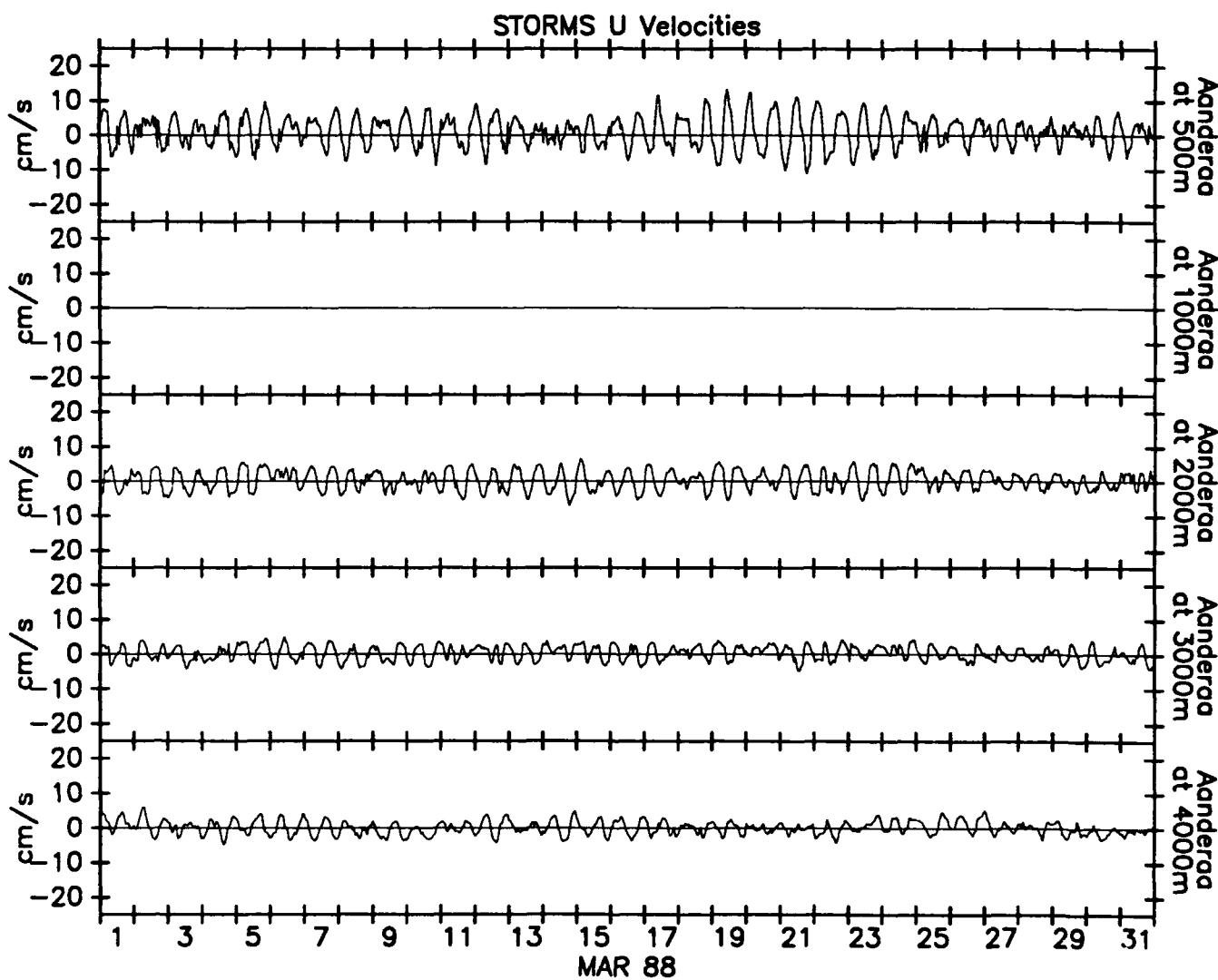


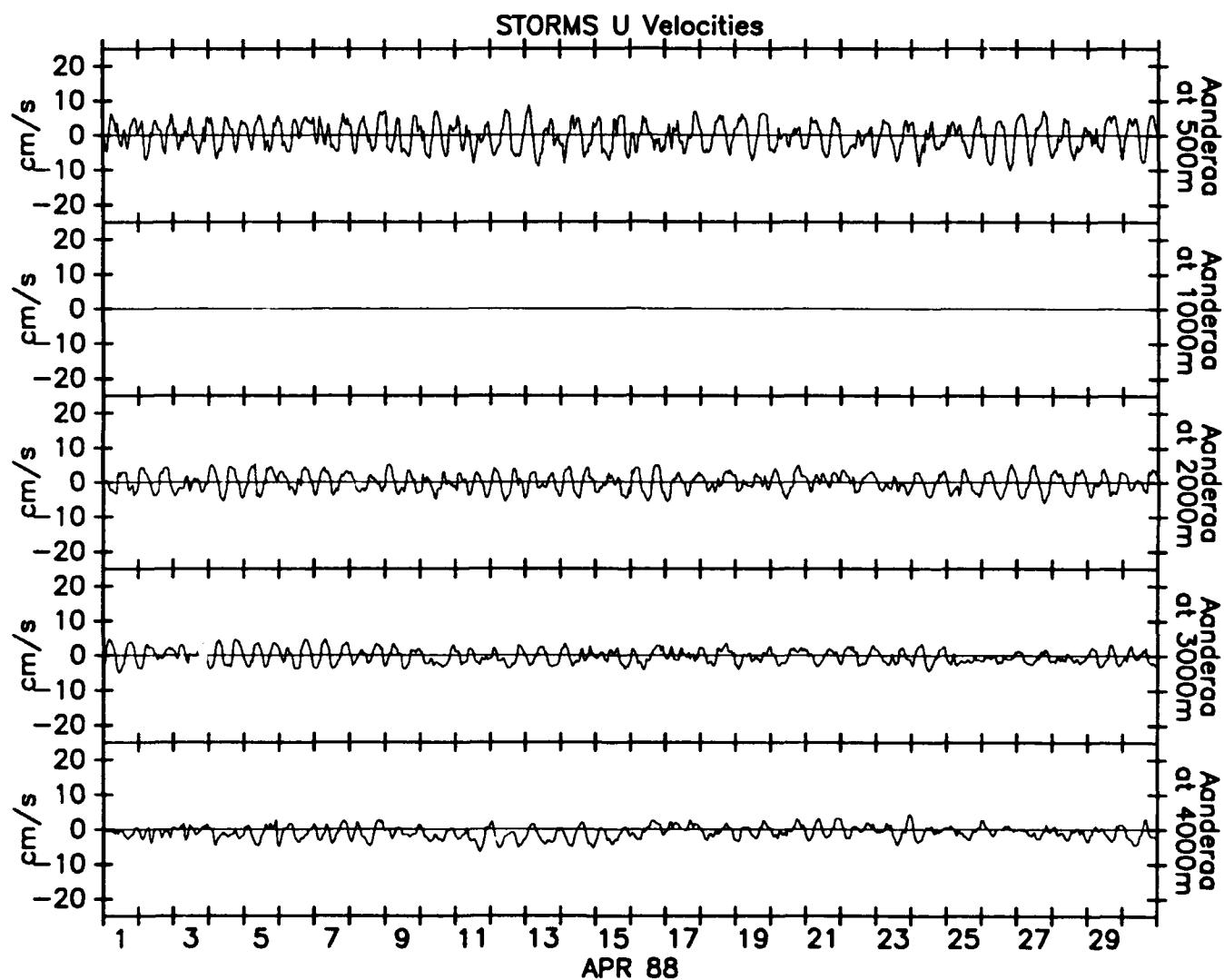


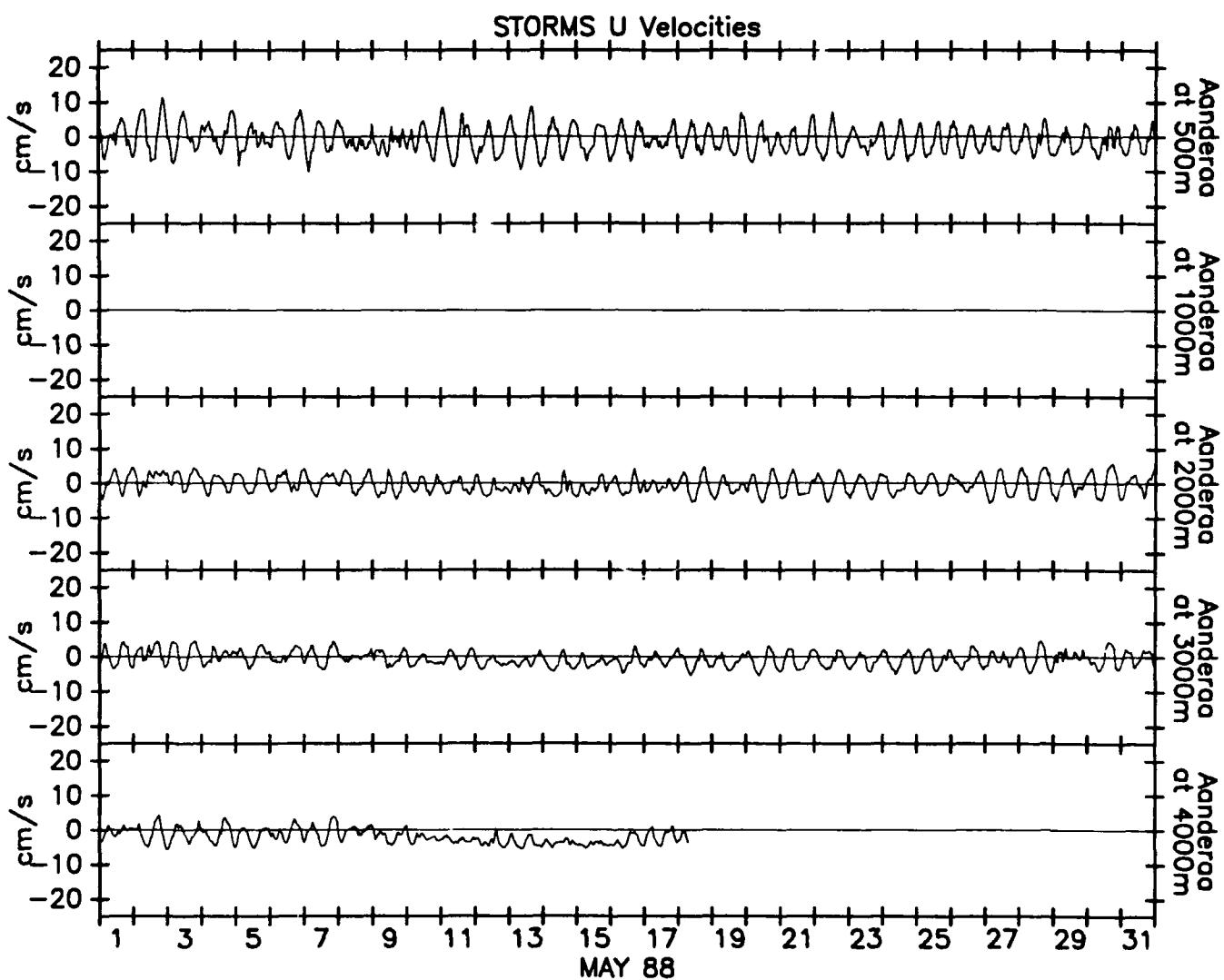


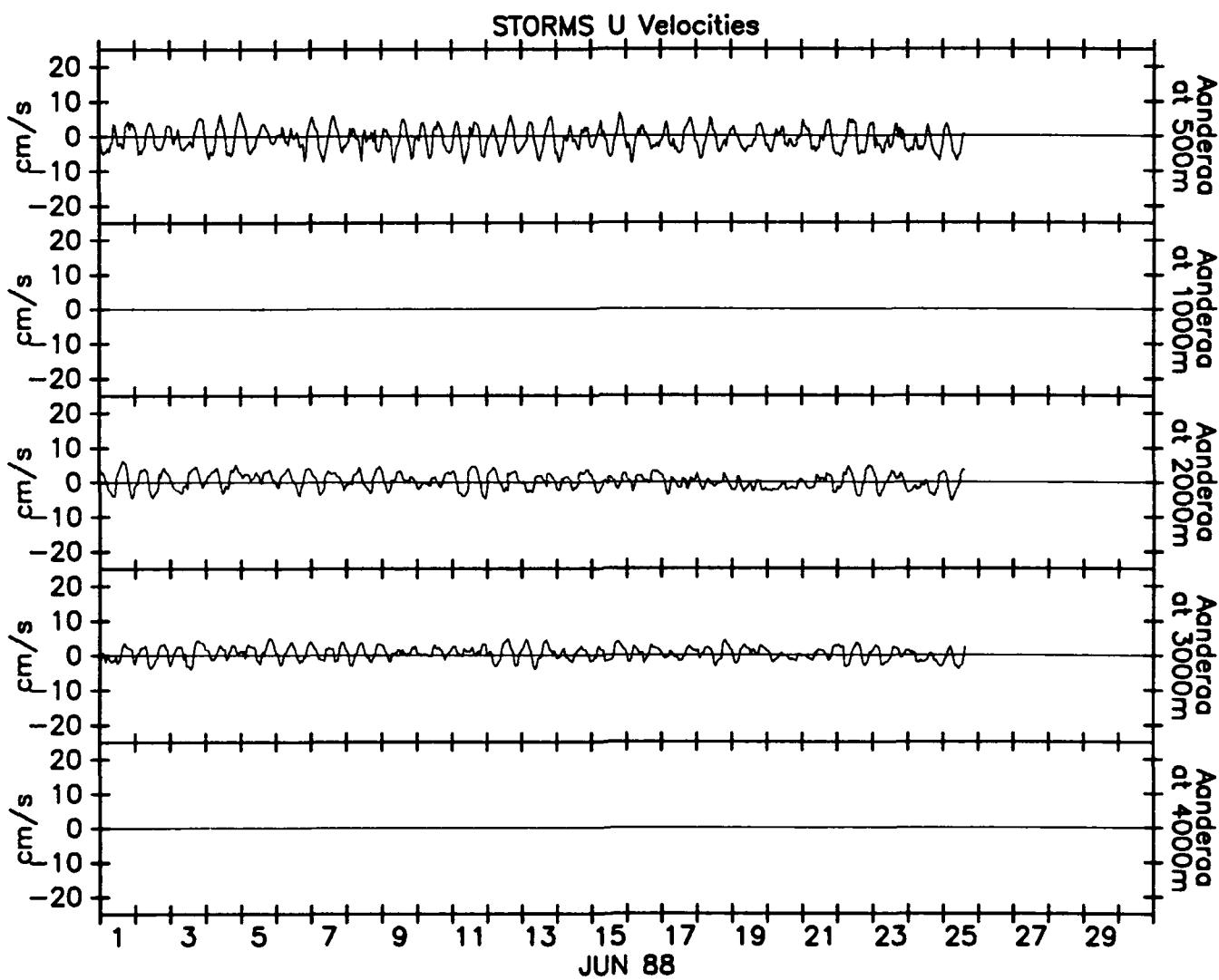


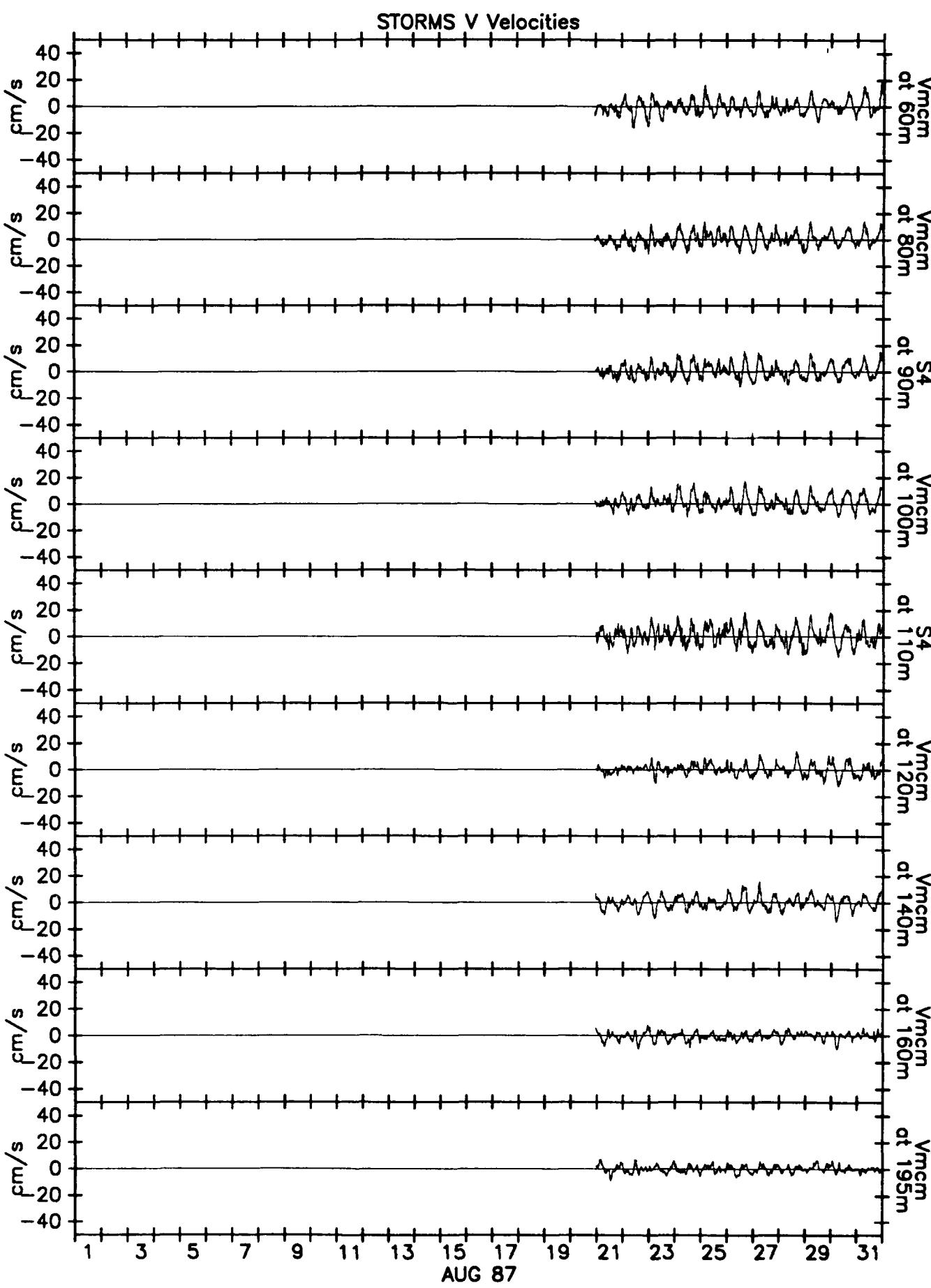


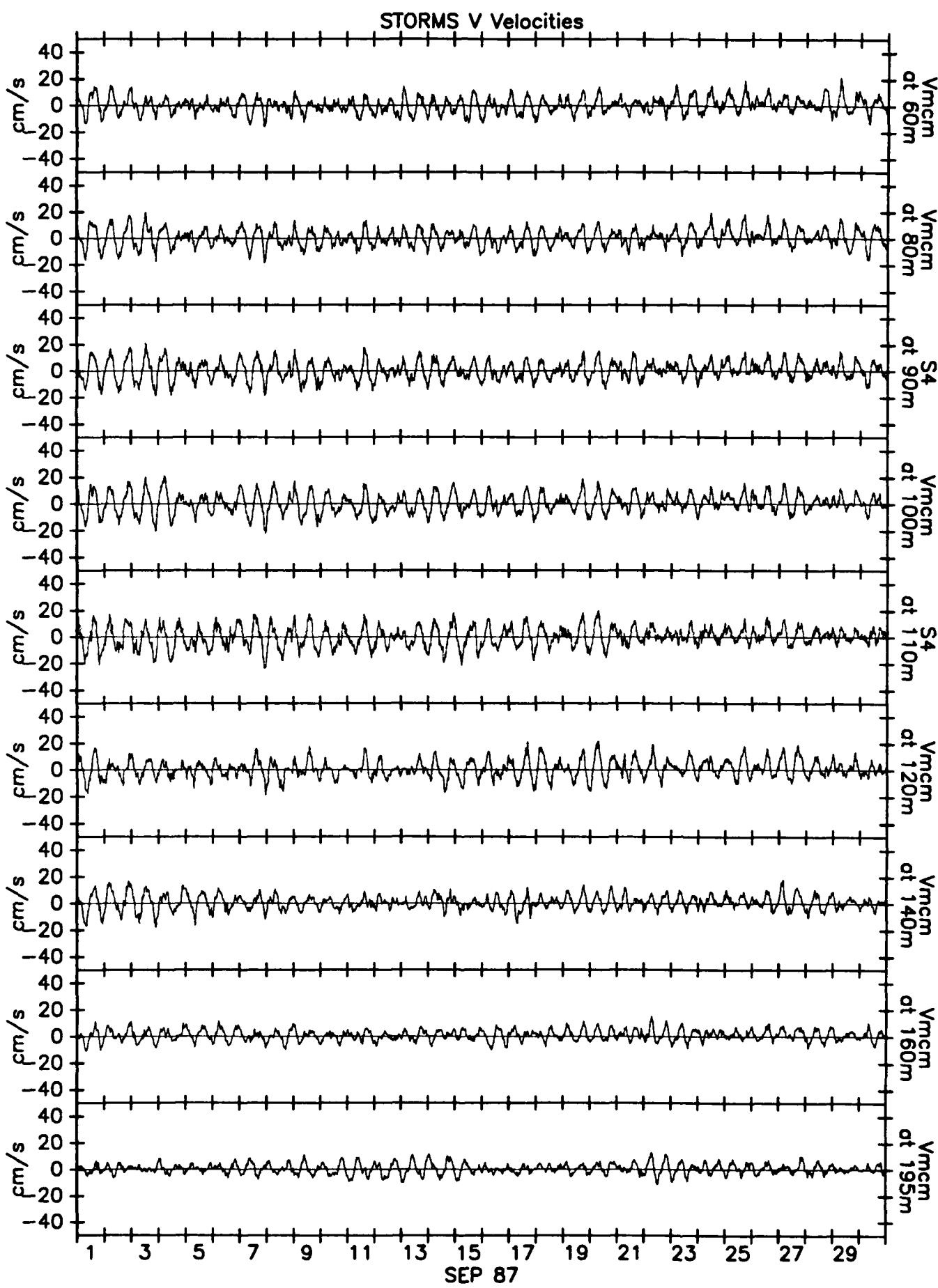




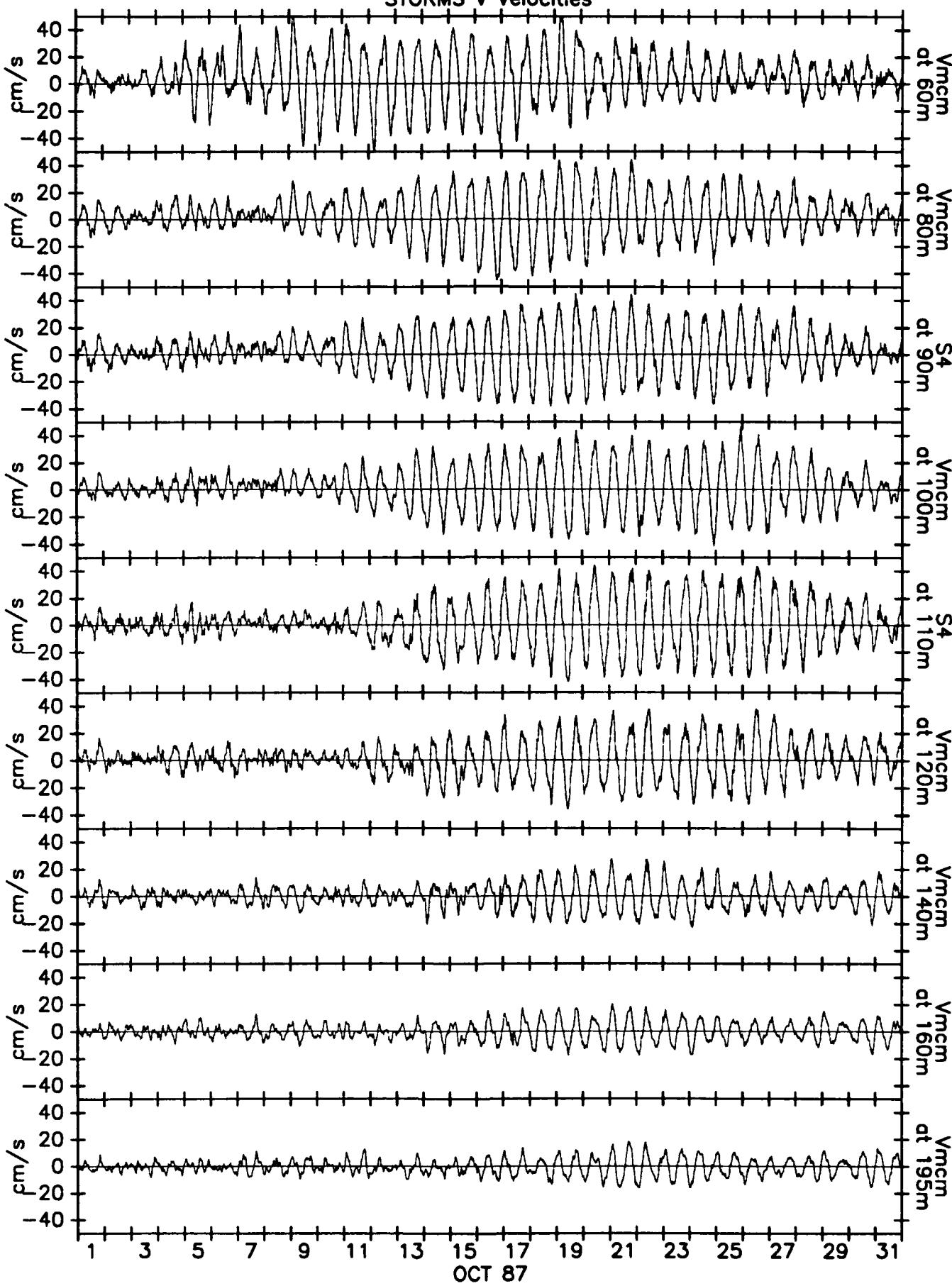


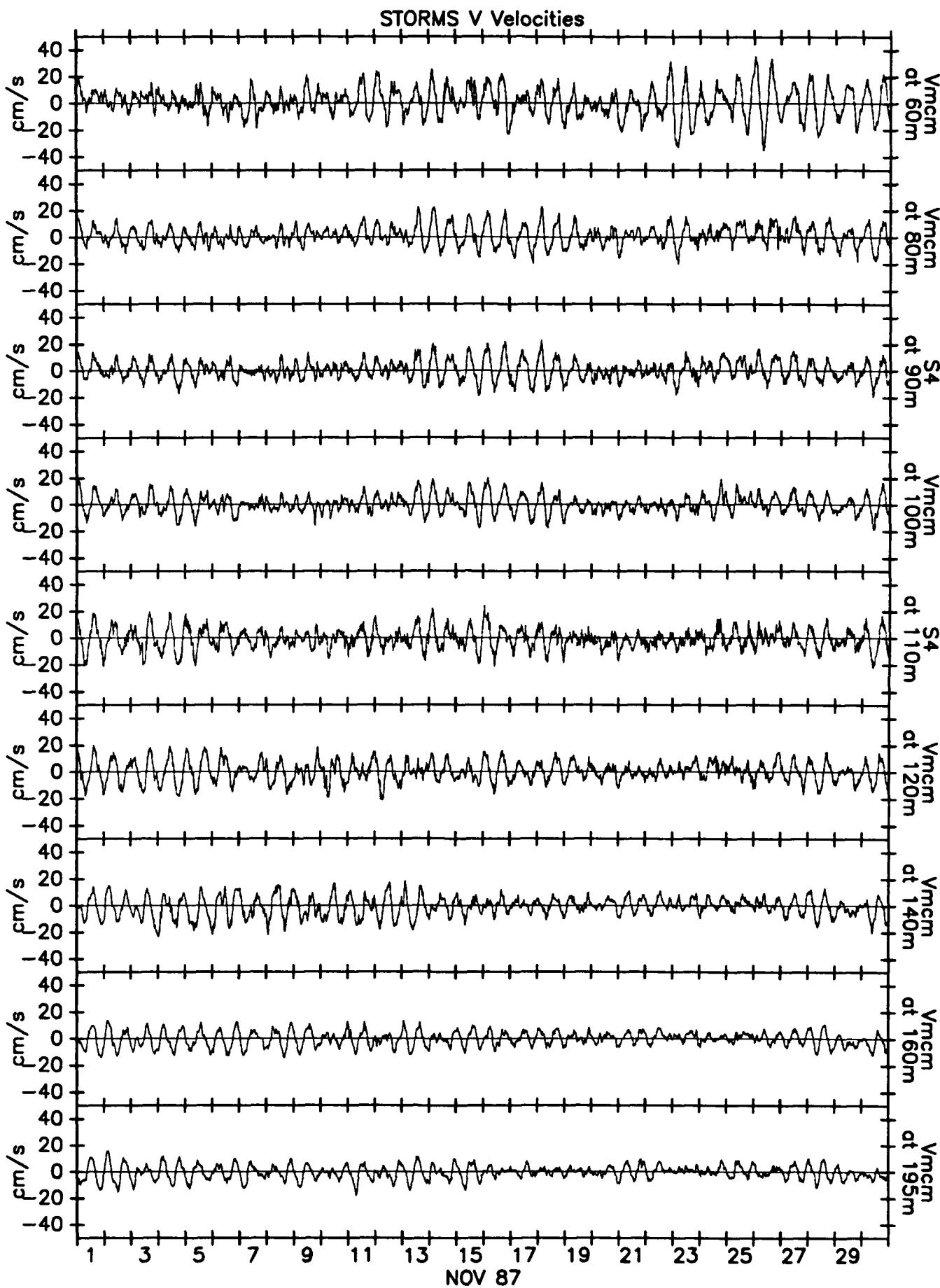




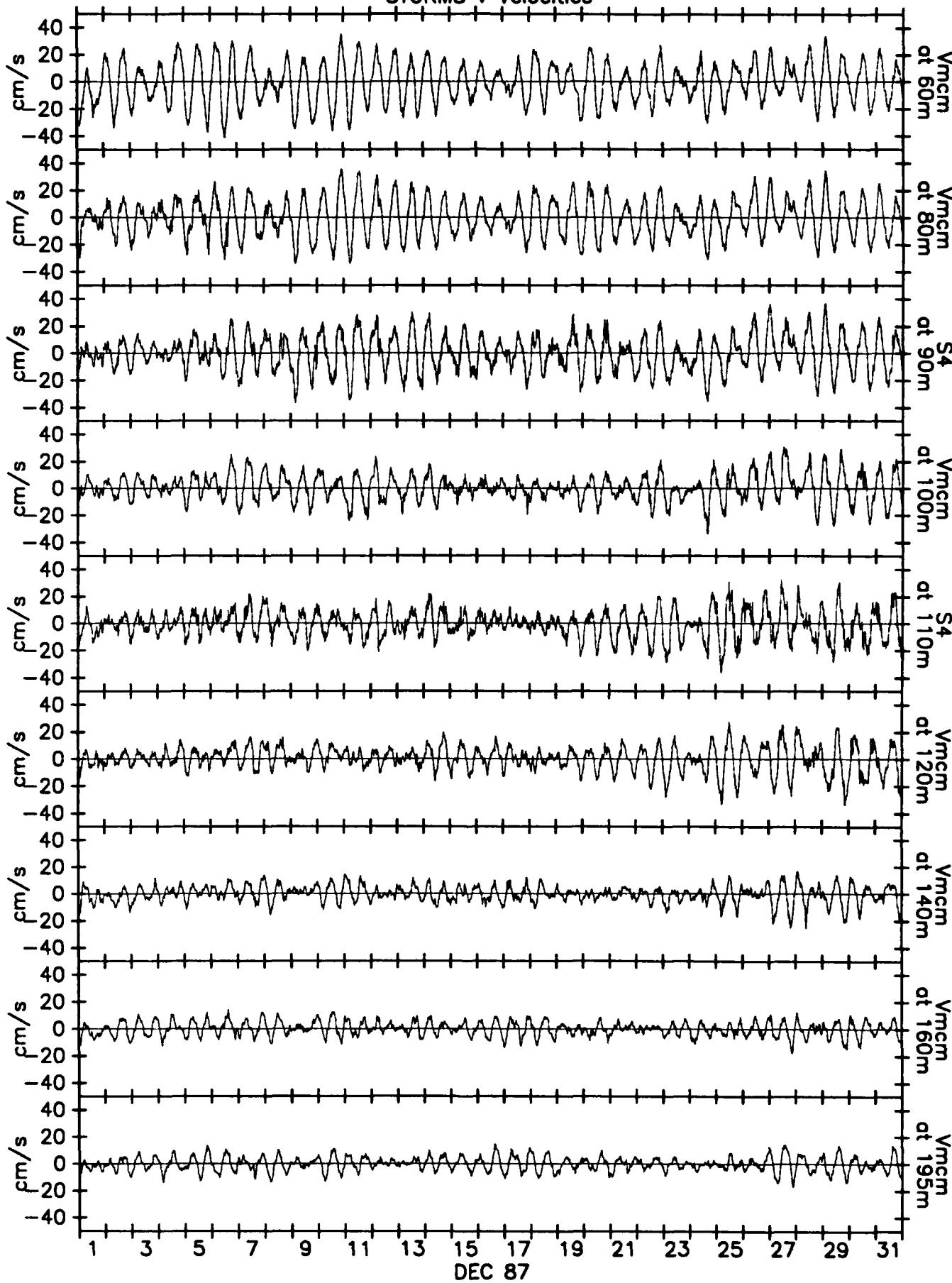


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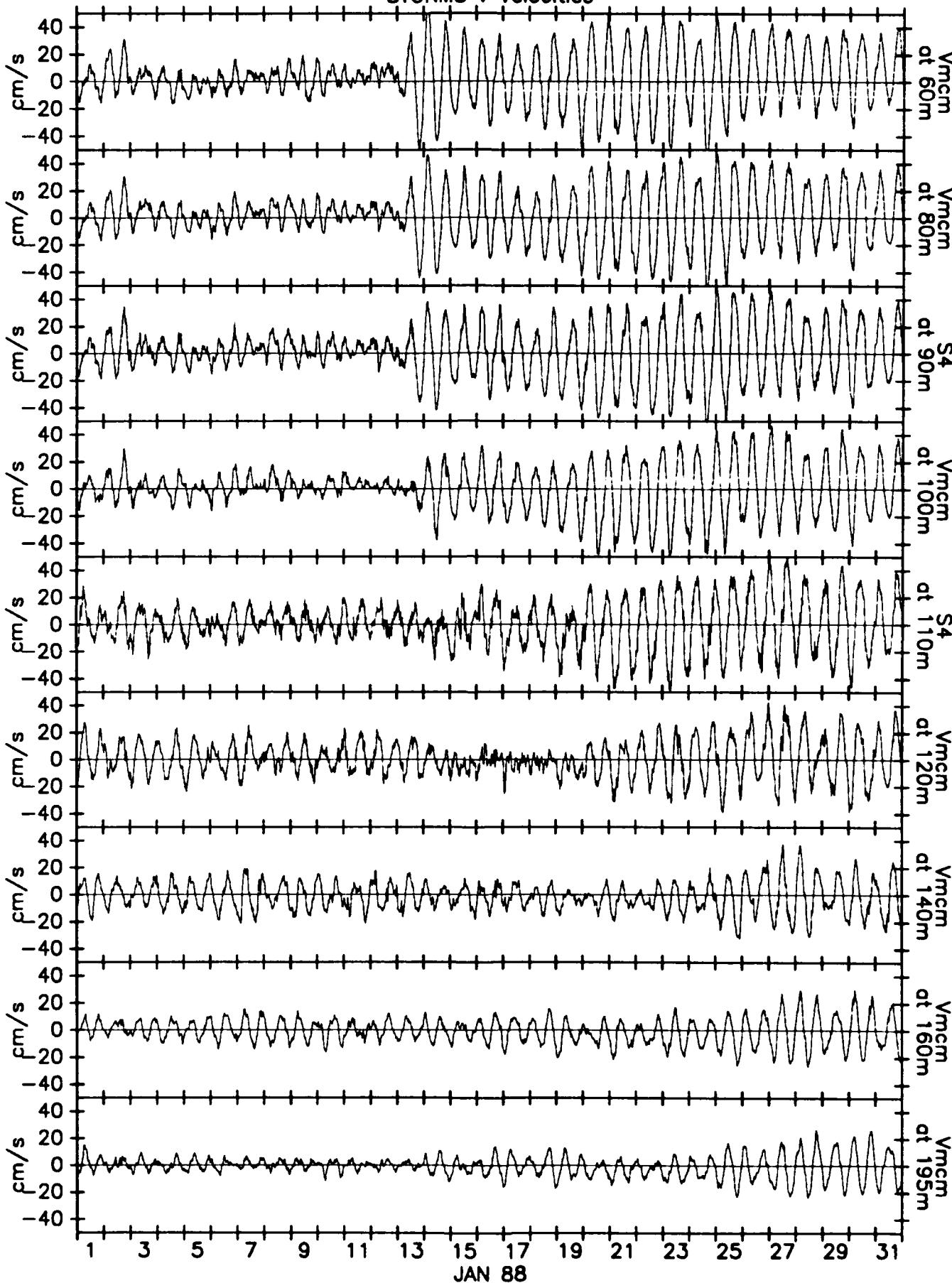


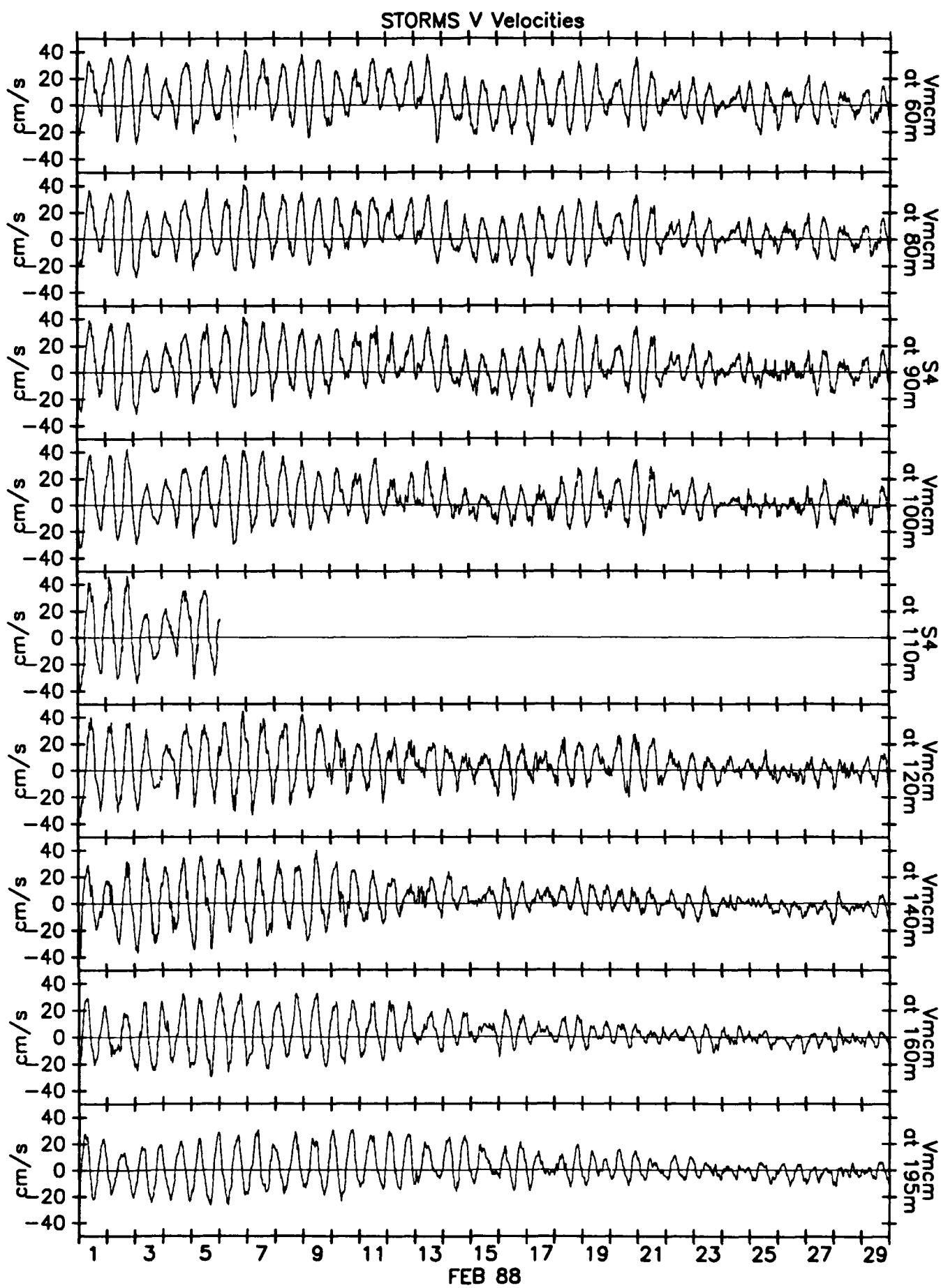


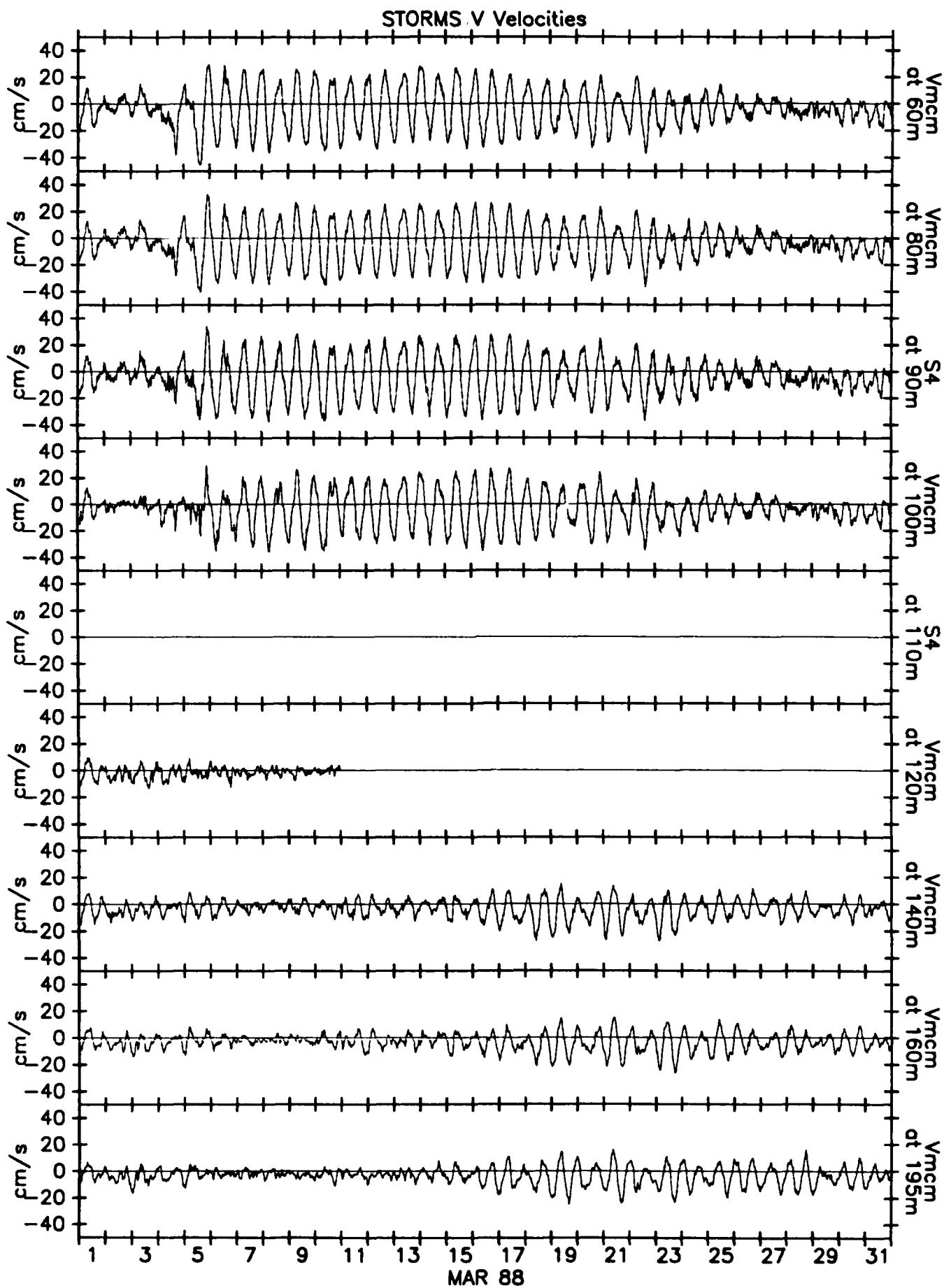
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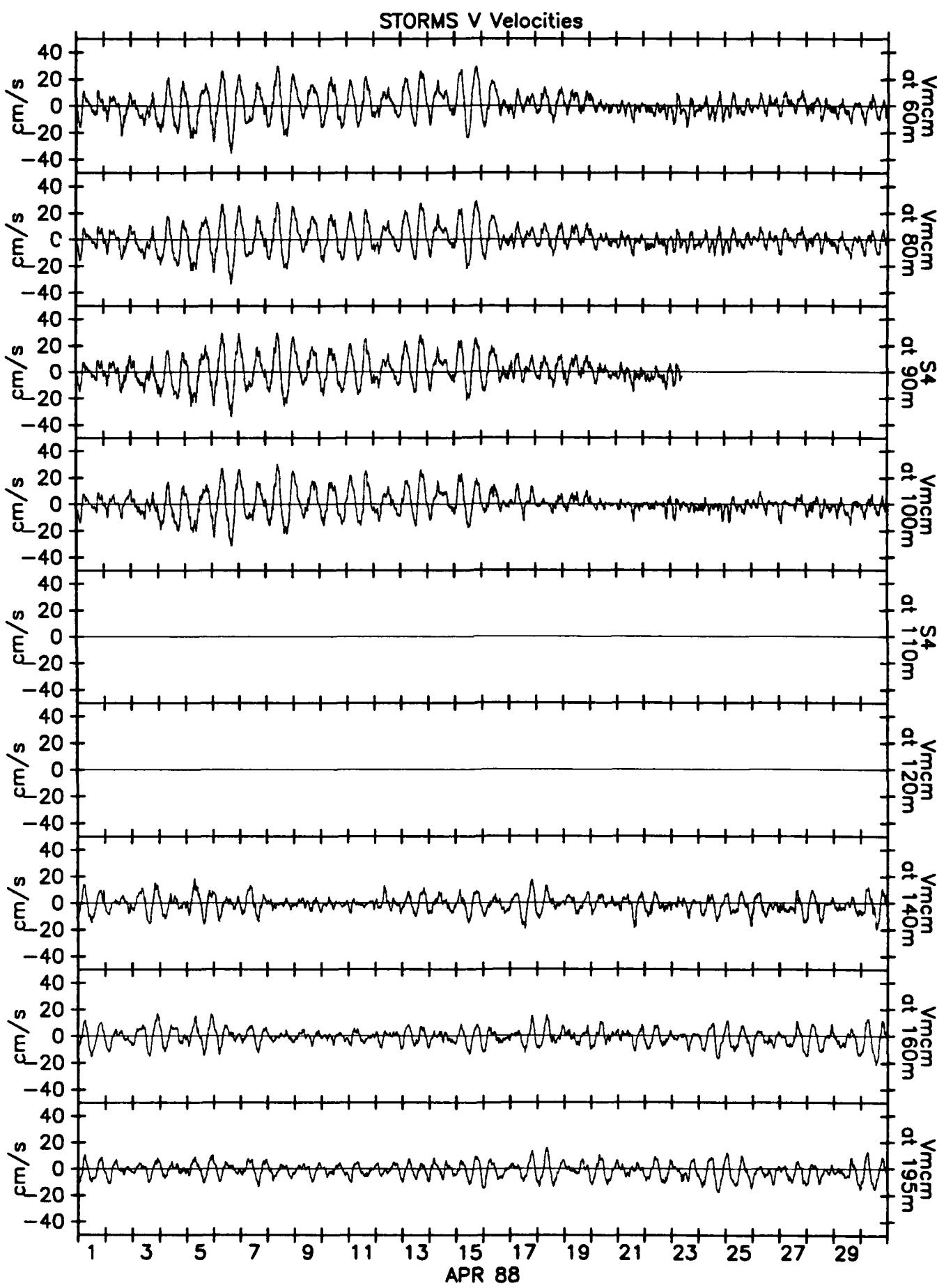


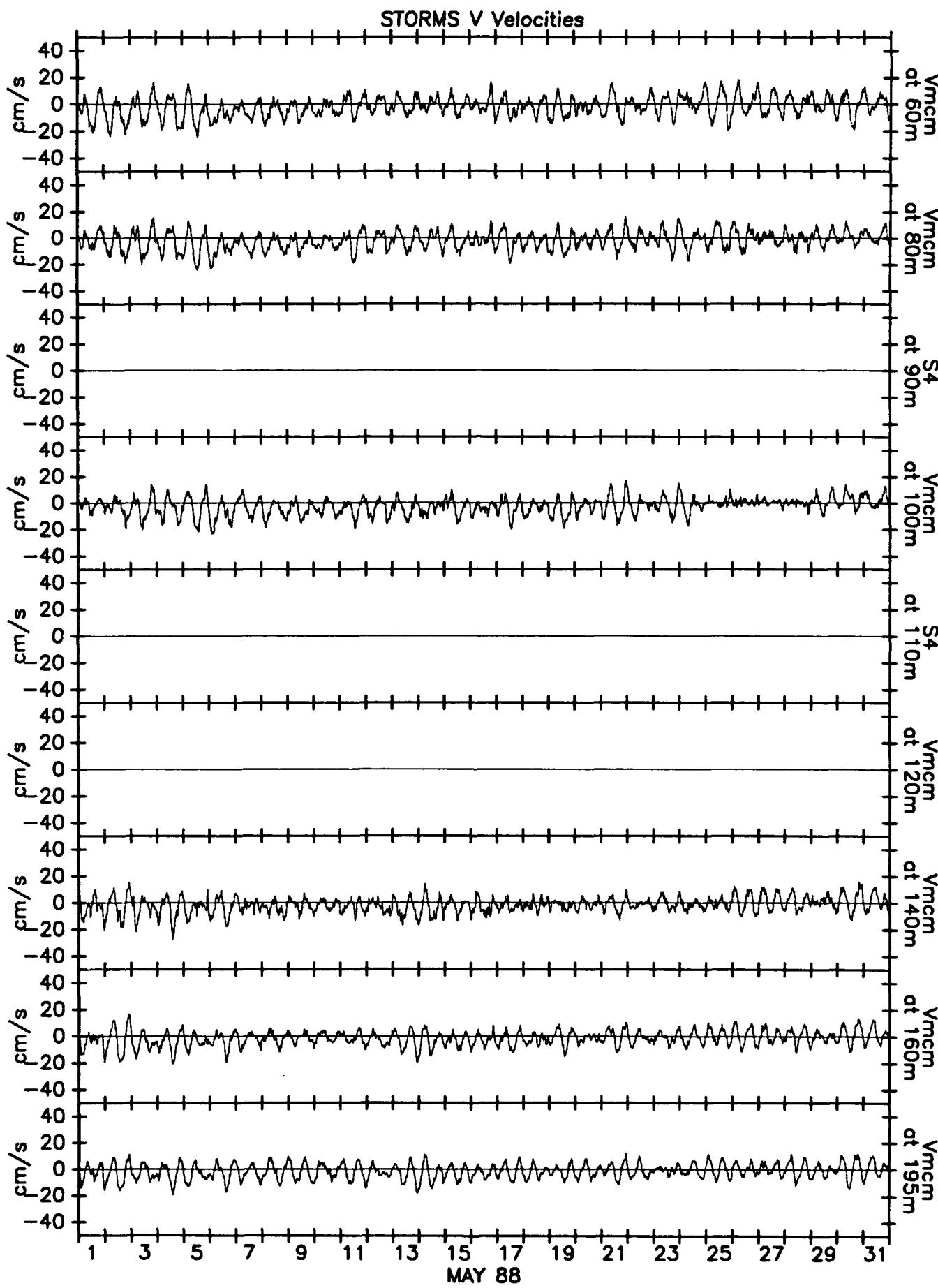
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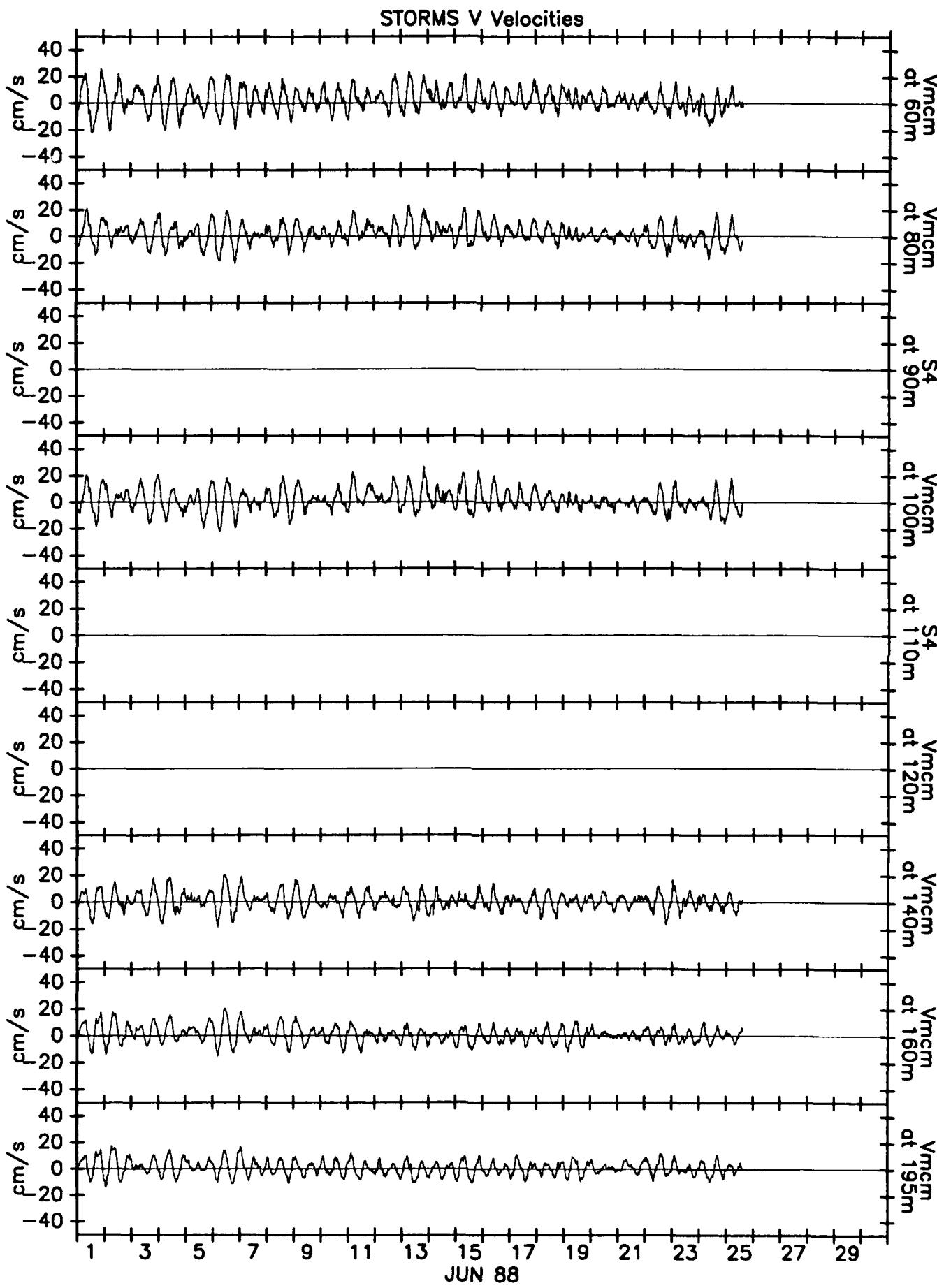


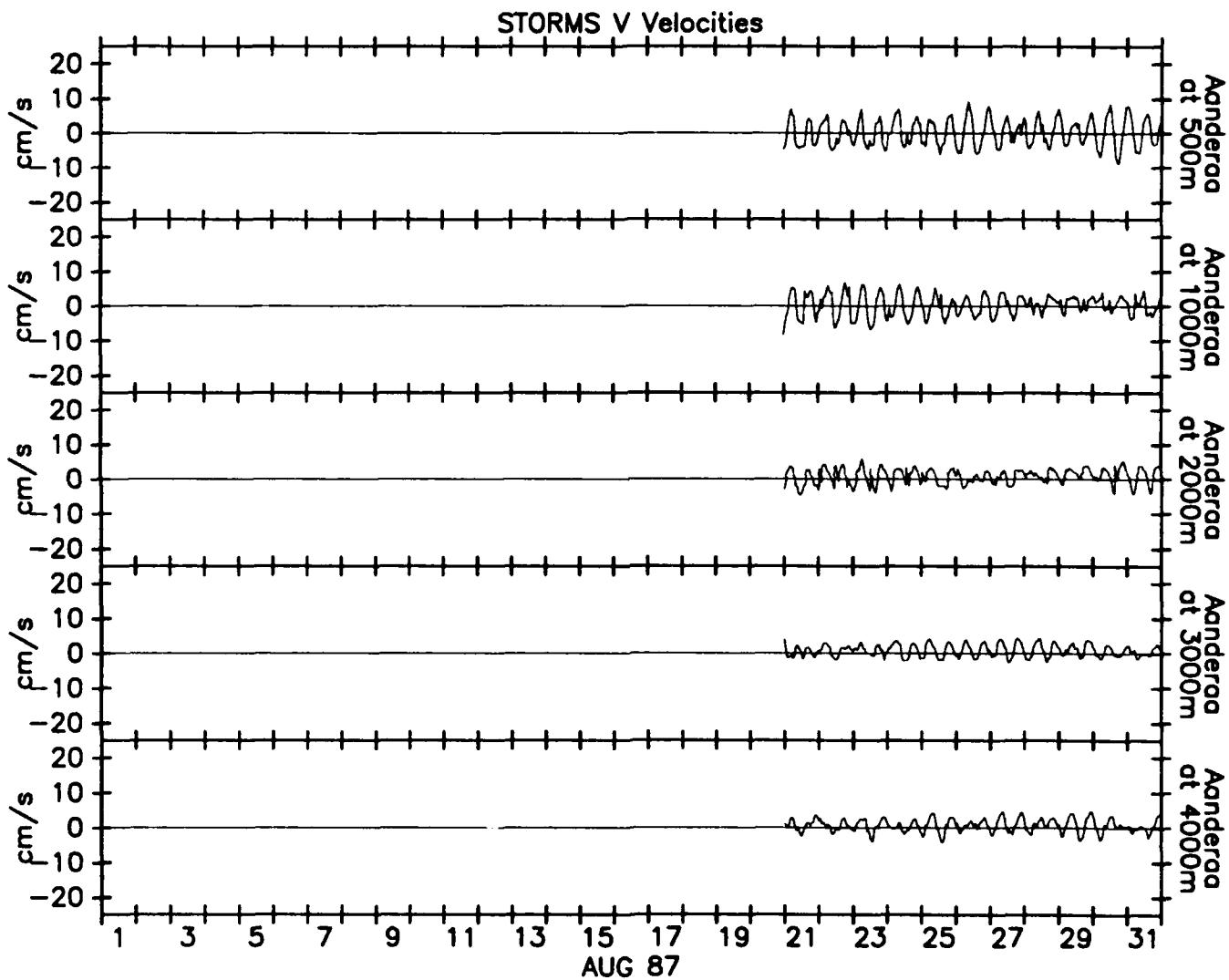


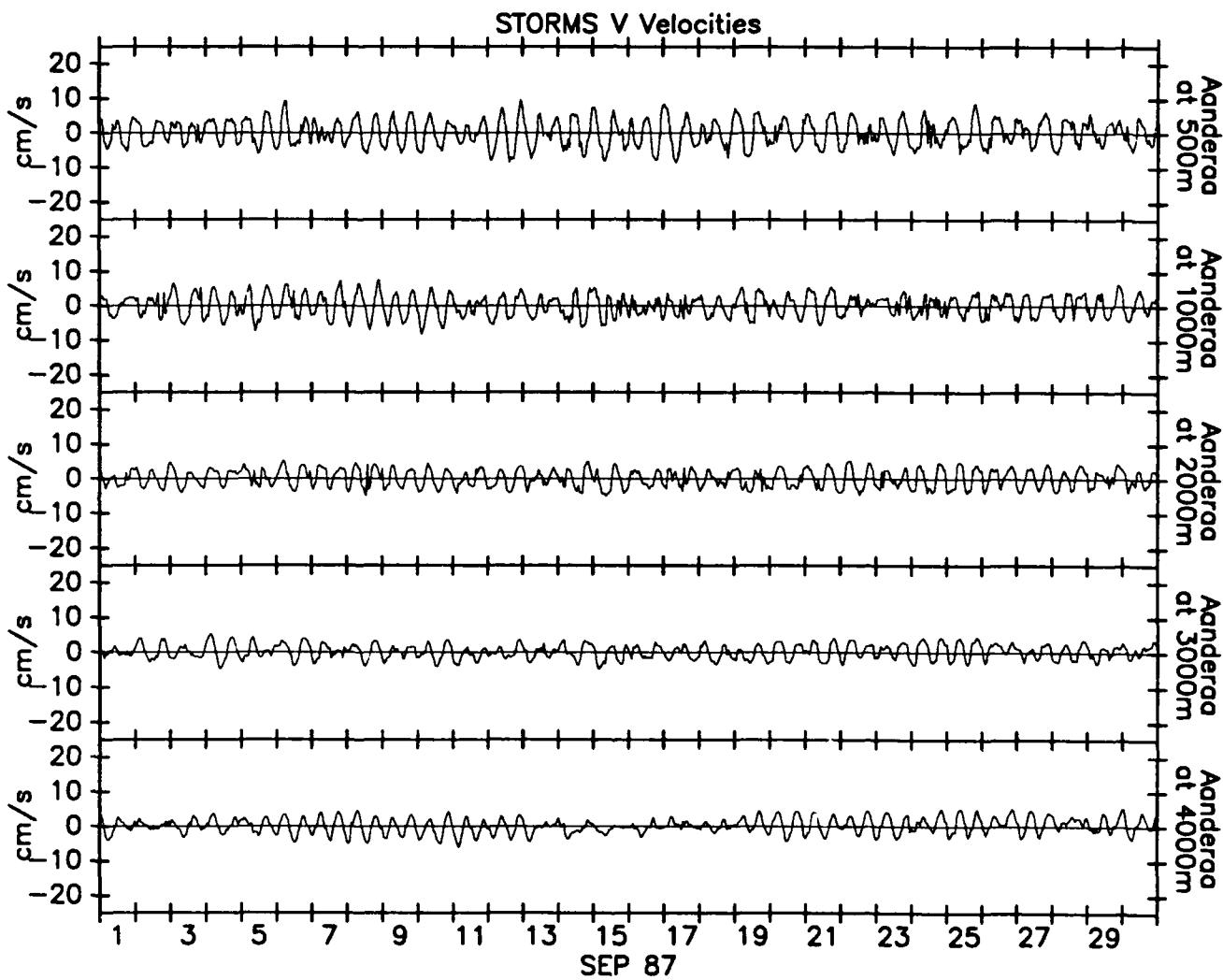


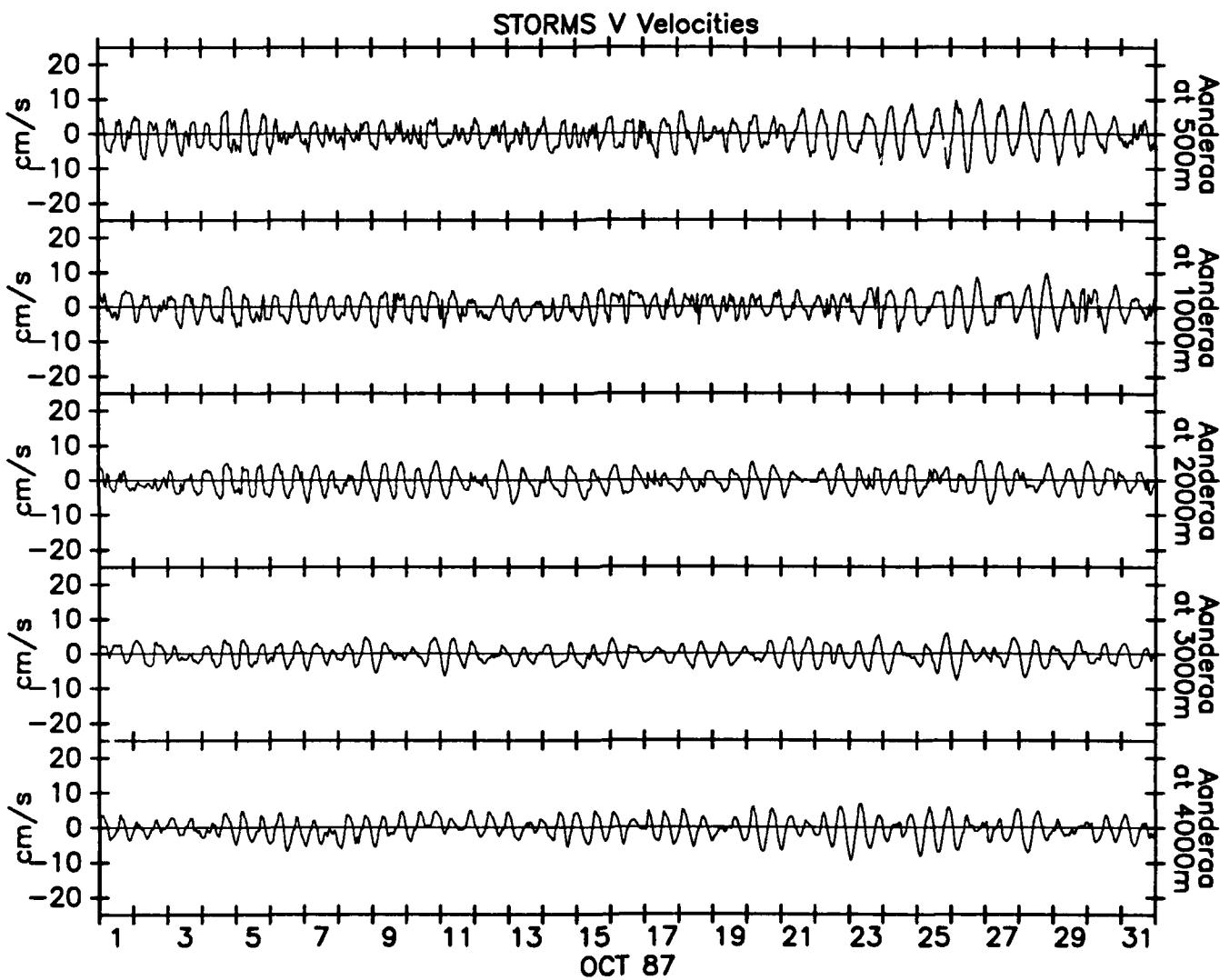


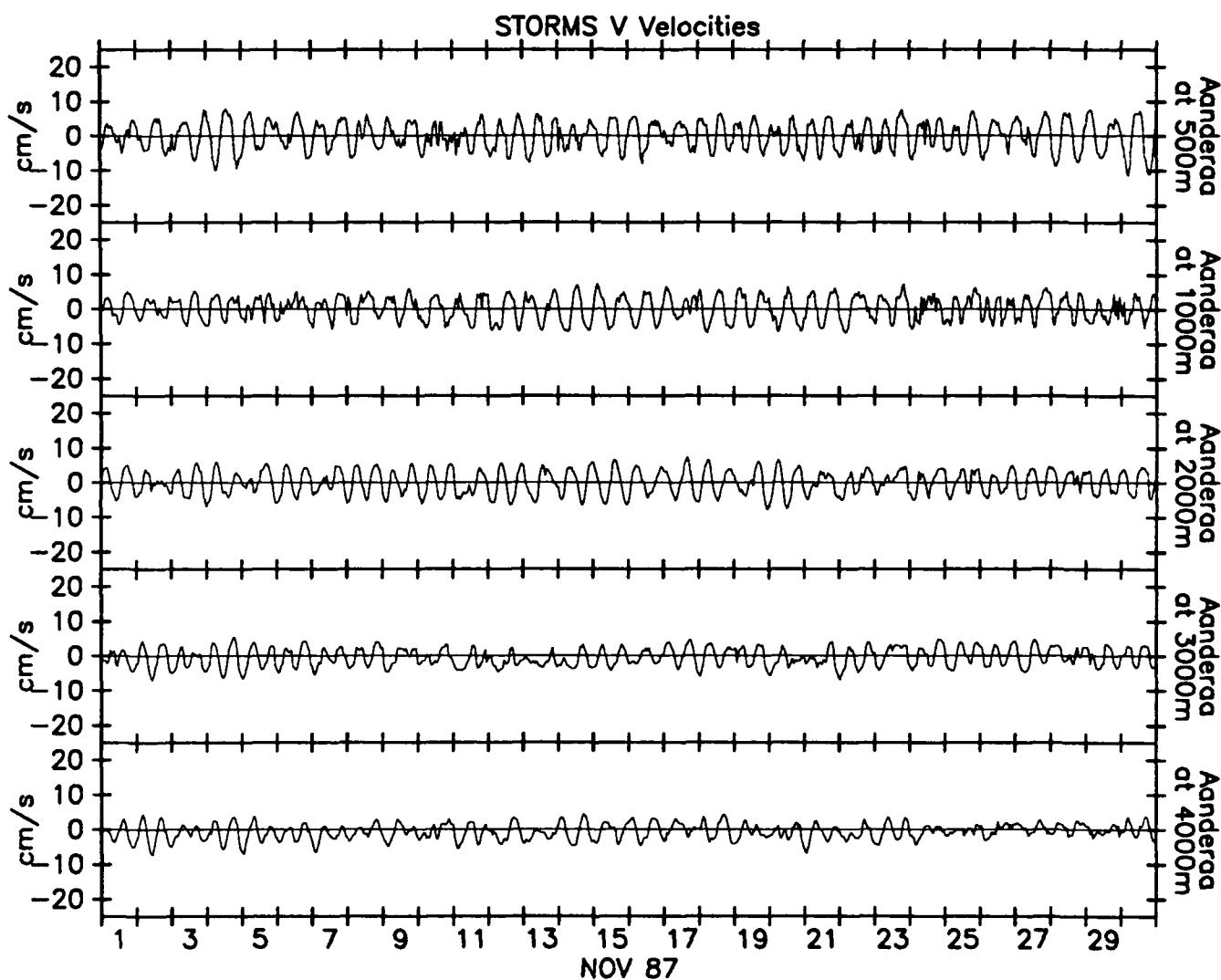


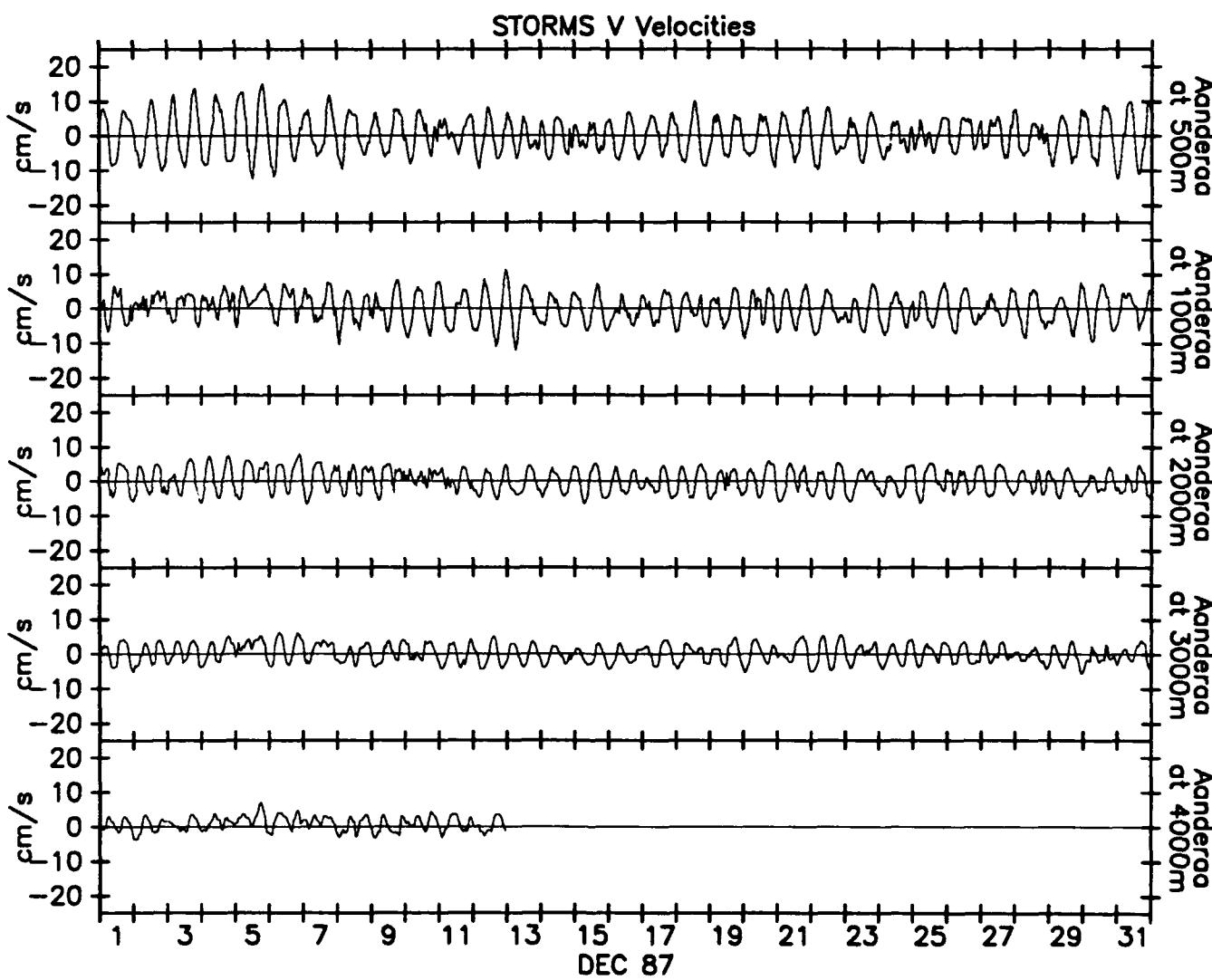


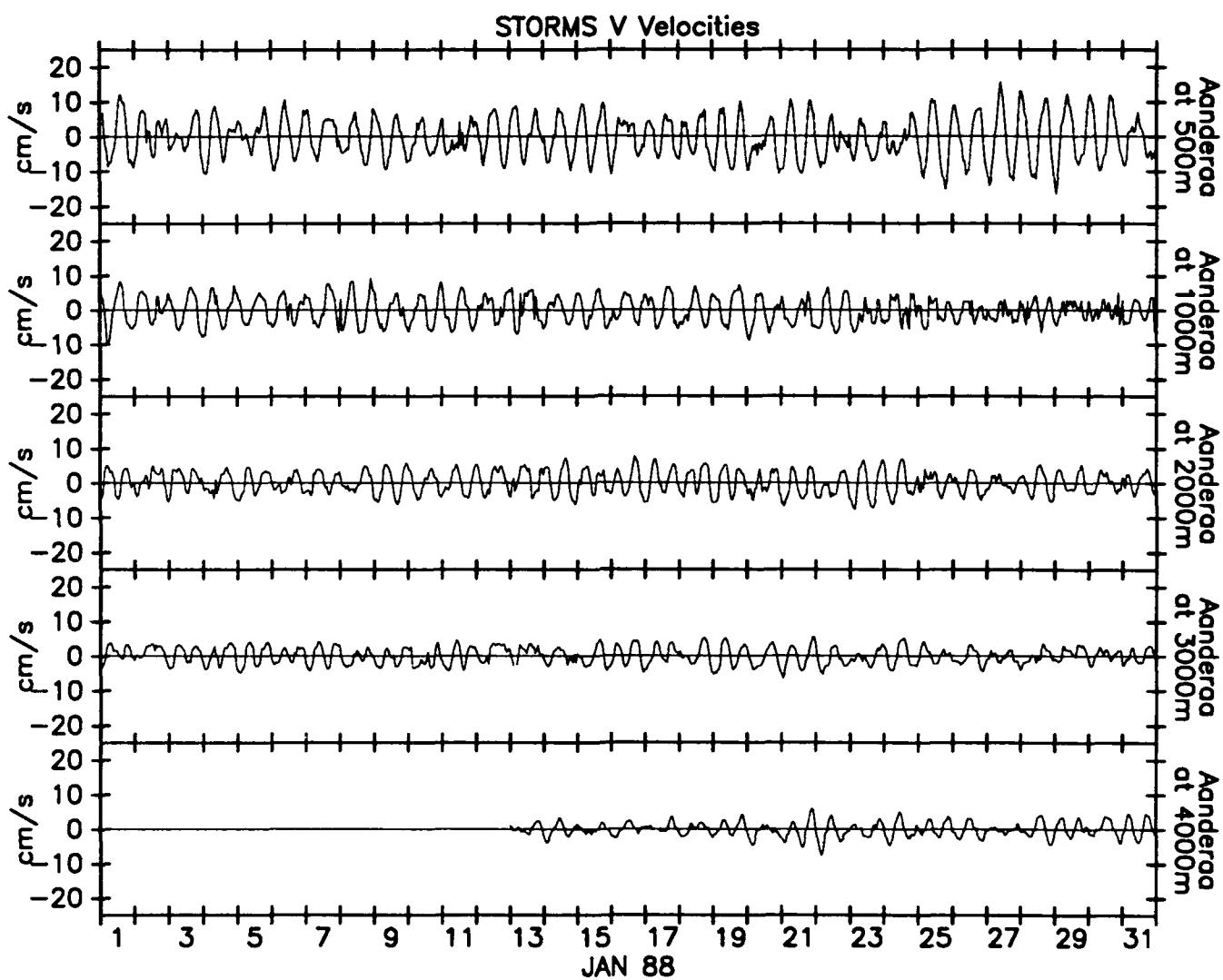


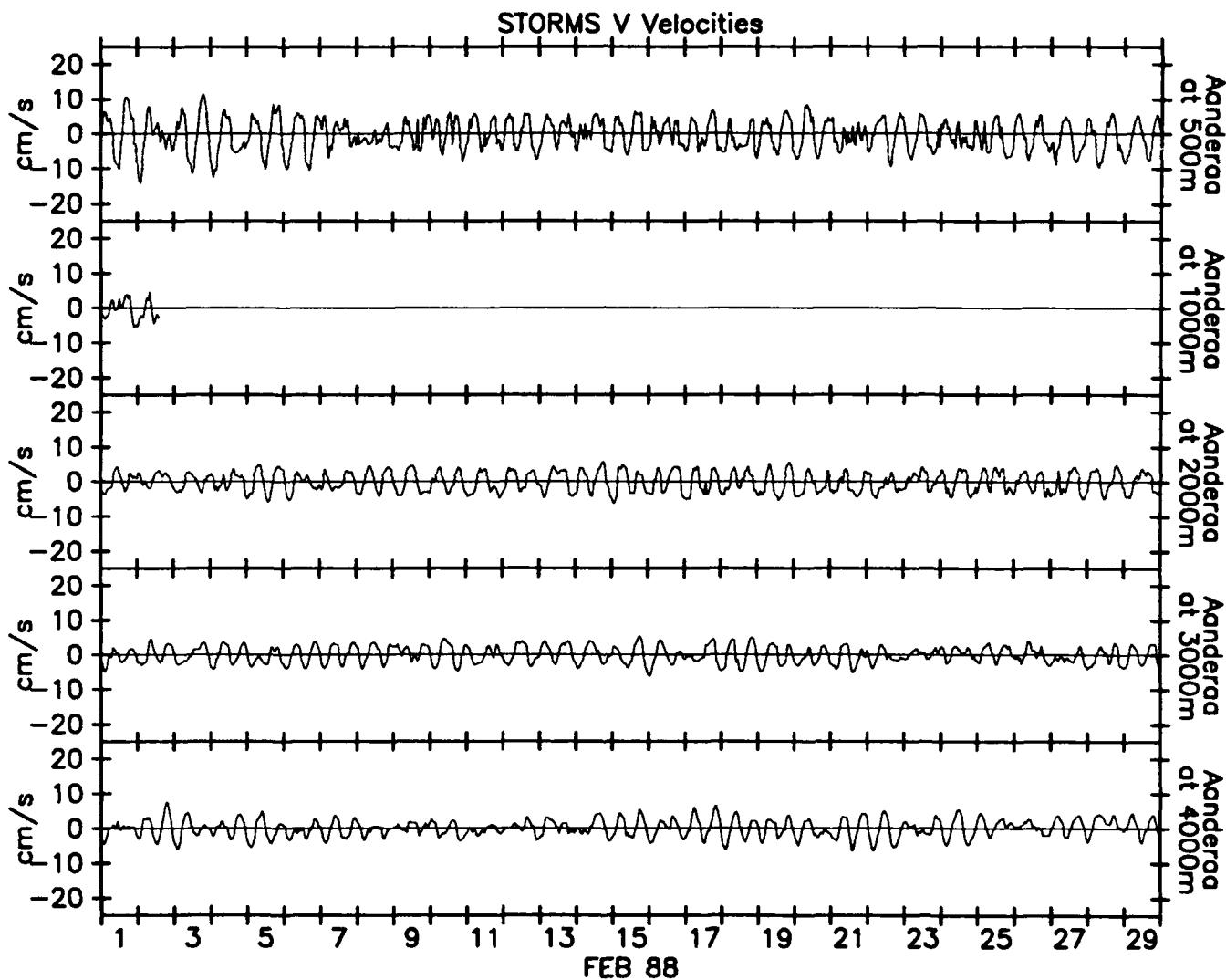


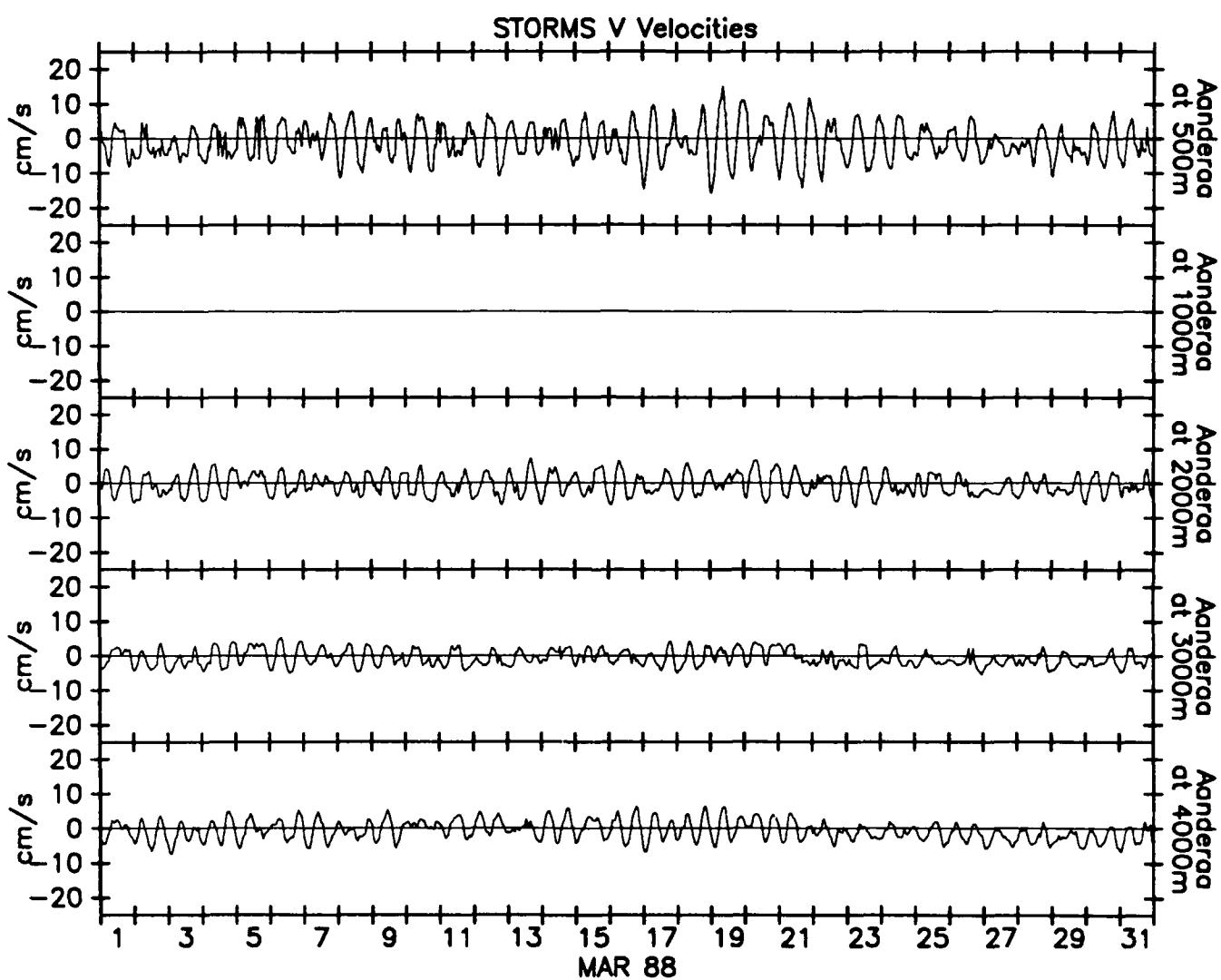


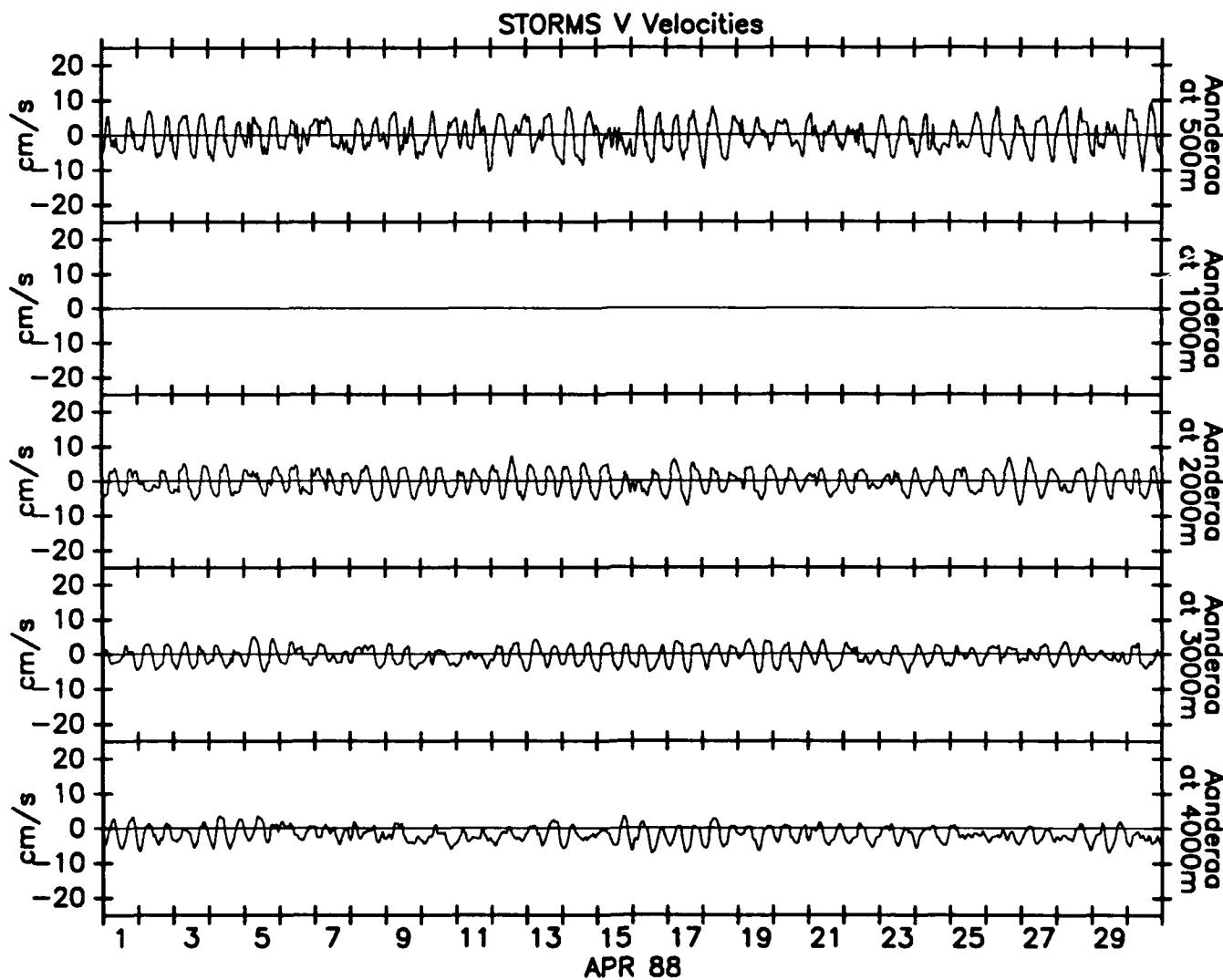


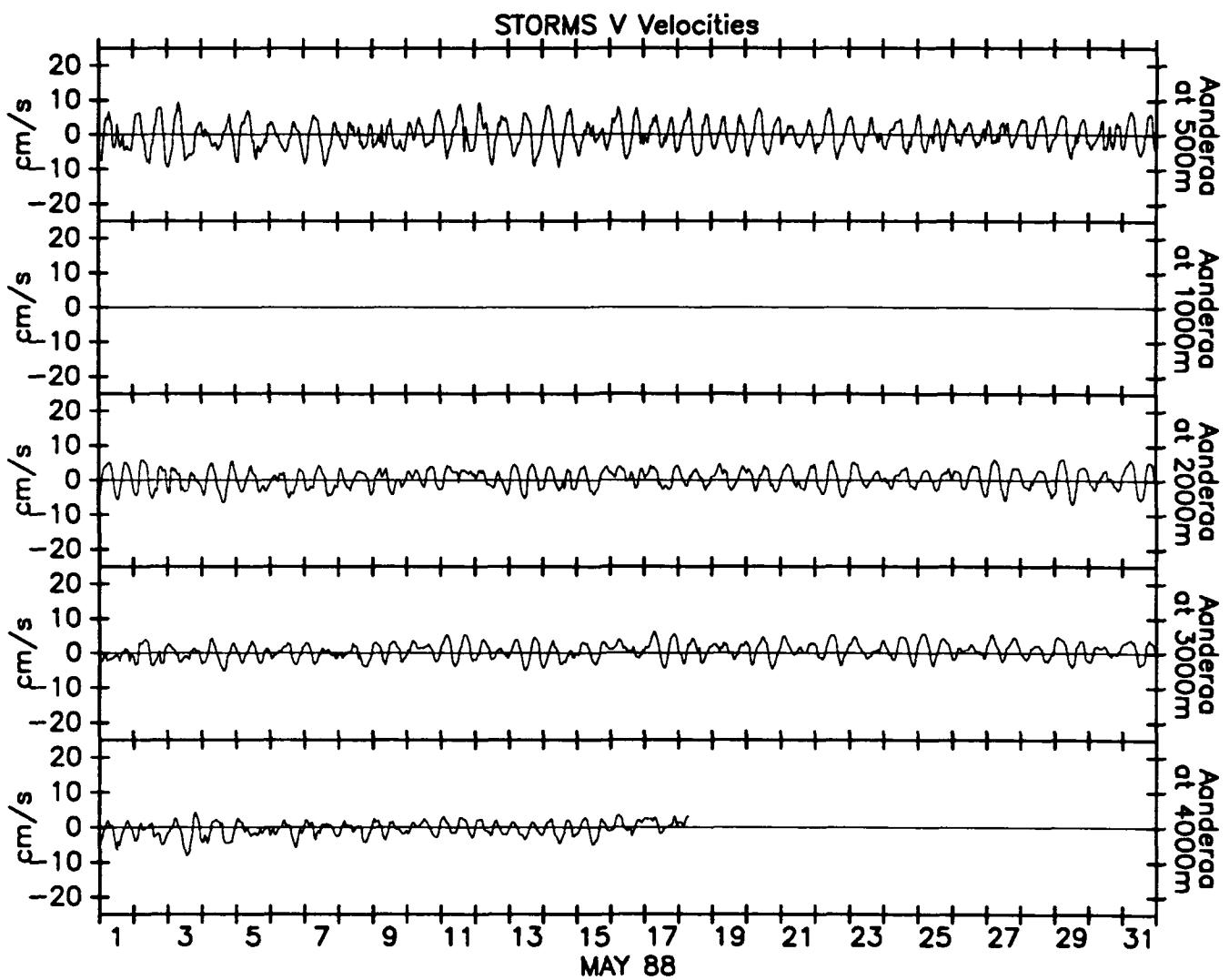


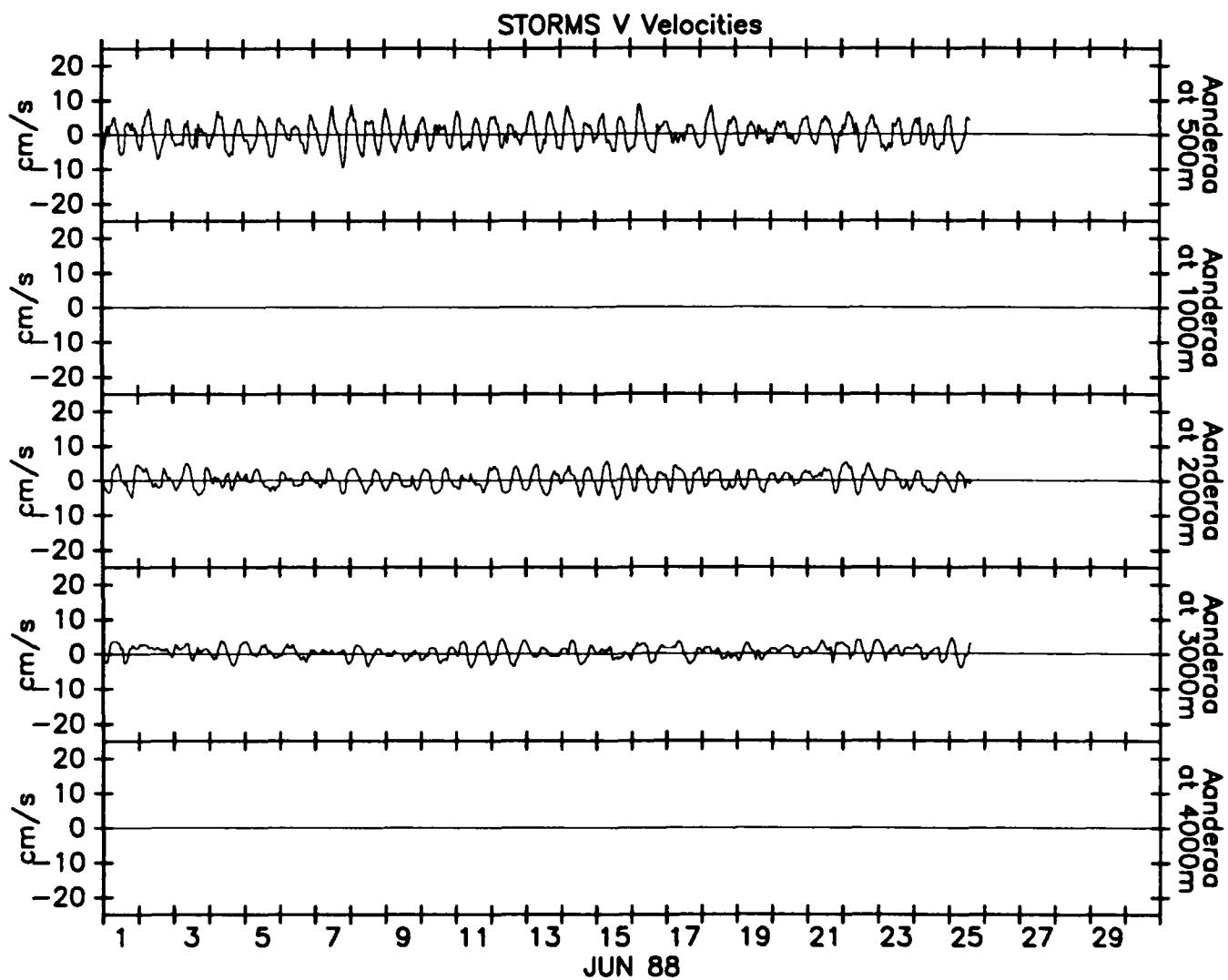












TIME SERIES OF PRESSURE

Observations are from pressure sensors attached to Seacats at 70 and 89 m.
Sampling rate was 1 hour before 3/4/88 and 2 hours after.

